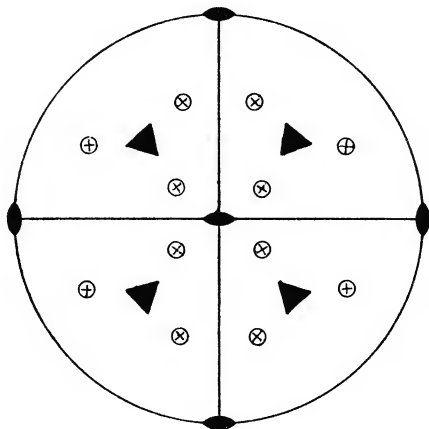
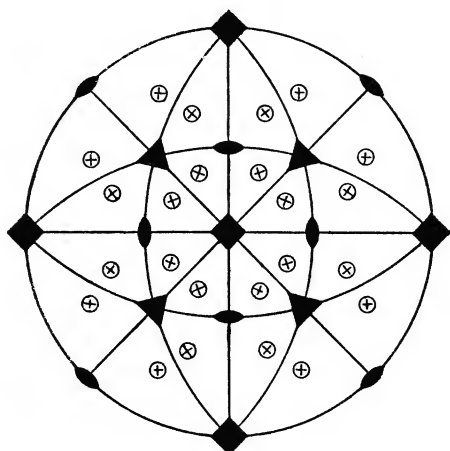


# A DOVER SCIENCE SAMPLER

SELECTED AND  
EDITED BY  
GEORGE BARKIN

A COLLECTION OF  
BRIEF NON-TECHNICAL  
PASSAGES FROM 44  
DOVER BOOKS  
EXPLAINING SCIENCE,  
FOR THE ENJOYMENT  
OF THE SCIENCE-  
MINDED BROWSER



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(Note: Some of the passages in the following collection have been  
 edited to make them as self-explanatory as possible.)

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## AN ARGUMENT FOR WIDER MARGINS

From "The Psychology of Invention in the Mathematical Field,"  
by Jacques Hadamard

If, in some exceptionally intuitive minds, ideas may evolve and combine in deep unconscious layers, then even important links of the deduction may remain unknown to the thinker himself who has found them. The history of science offers some remarkable examples.

Pierre de Fermat (1601-1661) was a magistrate, a counselor at the Parliament of Toulouse. It was a time when life was less complicated than nowadays, and the requirements of his duties apparently did not hamper him in his mathematical researches, which were considerable. Besides having participated in the origins of infinitesimal calculus and even in the creation of calculus of probabilities, he dealt actively with arithmetical questions. Among the ancient mathematicians whose works were in his possession, he owned a translation of the work of Diophantes, a Greek author who had dealt with such arithmetical subjects. Now, at Fermat's death, his copy of Diophantes' work was found to bear in the margin the following observation (in Latin):

"I have proved that the relation  $x^m + y^m = z^m$  is impossible in integral numbers ( $x, y, z$  different from 0;  $m$  greater than 2); but the margin does not leave me room enough to inscribe the proof."

Three centuries have elapsed since then, and that proof which Fermat could have written in the margin had the latter been a little broader, is still sought for. However, Fermat does not seem to have been mistaken, for partial proofs have been found, viz., proofs for some extended classes of values of the exponent  $m$ : for instance, the proof has been obtained for every  $m$  not greater than 100. But the work—an immense one—which made it possible to get these partial results could not be accomplished by direct arithmetical considerations: it required the help of some important algebraic theories of which no knowledge existed in the time of Fermat and no conception appears in his writings.

## ASTRONOMY AND COMMON SENSE

From "A History of Astronomy from Thales to Kepler,"

by J. L. E. Dreyer

There were those who would have nothing to do with anything that came from the pre-Christian world, and to whom even "the virtues of the heathen were but splendid vices." A typical representative of these men was Lactantius, the first and the worst of the adversaries of the rotundity of the earth, whose seven books on "Divine Institutions" seem to have been written between A. D. 302 and 323. In the third book, "On the false wisdom of the philosophers," the 24th chapter is devoted to heaping ridicule on the doctrine of the spherical figure of the earth and the existence of antipodes. It is unnecessary to enter into particulars as to his remarks about the absurdity of believing that there are people whose feet are above their heads, and places where rain and hail and snow fall upwards, while the wonder of the hanging gardens dwindles into nothing when compared with the fields, seas, towns, and mountains, supposed by philosophers to be hanging without support. He brushes aside the argument of philosophers that heavy bodies seek the centre of the earth as unworthy of serious notice; and he adds that he could easily prove by many arguments that it is impossible for the heavens to be lower than the earth, but he refrains because he has nearly come to the end of his book, and it is sufficient to have counted up some errors, from which the quality of the rest may be imagined.

## THE STUDY OF ANATOMY REVIVES— AFTER A FASHION

From "A Short History of Anatomy and Physiology;  
from the Greeks to Harvey," by Charles Singer

It is not easy to find evidence of Nature-study in the thirteenth or fourteenth century, nor any enthusiasm for putting theoretical considerations to practical tests in that age. There was still no Botany worthy of the name, no Zoology, hardly any naturalistic Art, no experimental Science, no systematic observation in any department. Yet dissection had become comparatively common at Bologna by the end of the first quarter of the fourteenth century. The question is asked why men, obviously so little interested in Nature and Nature's way, should have bent themselves to so repellent a process as dissection of the human body in order to seek out the secrets of Nature. The answer is that, in fact, they did nothing of the sort. Dissection in the fourteenth century did no more, and was asked to do no more, than

verify Avicenna, the great Arab physician and philosopher of the 11th century—whom nobody doubted. It seems probable that the earliest reason for examining the human body was simply the gathering of evidence for legal processes. This is a reason, and the only reason, that would have appealed to an official of Bologna University of the thirteenth century. As time went on post-mortem examination passed into anatomical study.

But as dissection gained formal inclusion in the curriculum, the professor became further removed from the object of his study. He literally "rose with his subject." Leaving his position by the cadaver where he might demonstrate to his students, he ascended his high professional chair. The "chair" of a professor was very much of a physical reality in those days; a great elevated structure provided with steps and a reading desk, something like a pulpit. From there he read or lectured while a junior colleague or *ostensor* pointed out the line of incision and a menial *demonstrator* performed the actual dissection. Having once got into his chair, the professor did not willingly descend from that dignified position. Mondino de' Luzzi carried out the first great reform in anatomy by stepping down from his chair and dissecting *in person*. But even though Mondino is with justice called the "Restorer of Anatomy," we observe that, though dissecting on his own account, he is yet relying almost entirely on Arabian authorities. He is really dissecting to memorize his textbook, not to enlarge knowledge or to make discoveries. The scientific spirit has hardly awakened in Mondino.

## MINERS, TAKE HEED!

From "De Re Metallica," (1556) by Georgius Agricola

There are many great contentions between miners concerning the forked twig, for some say that it is of the greatest use in discovering veins, and others deny it. Some of those who manipulate and use the twig, first cut a fork from a hazel bush with a knife, for this bush they consider more efficacious than any other for revealing the veins, especially if the hazel bush grows above a vein. Others use a different kind of twig for each metal, when they are seeking to discover the veins, for they employ hazel twigs for veins of silver; ash twigs for copper; pitch pine for lead and especially tin, and rods made of iron and steel for gold. All alike grasp the forks of the twig with their hands, clenching their fists, it being necessary that the clenched fingers should be held toward the sky in order that the twig should be raised at that end where the two branches meet. Then they wander hither and thither at random through mountainous regions. It is said that the moment they place their feet on a vein the twig immediately turns and



twists, and so by its action discloses the vein; when they move their feet again and go way from that spot the twig becomes once more immobile.

It is a conspicuous fact that these cunning manipulators do not use a straight twig, but a forked one cut from a hazel bush, or from other wood equally flexible, so that if it be held in the hands, as they are accustomed to hold it, it turns in a circle for any man wherever he stands. Nor is it strange that the twig does not turn when held by the inexperienced, because they either grasp the forks of the twig too tightly or hold them too loosely. Nevertheless, these things give rise to the faith among common miners that veins are discovered by the use of twigs, because whilst using these they do accidentally discover some; but it more often happens that they lose their labor, and although they might discover a vein, they become none the less exhausted in digging useless trenches than do the miners who prospect in an unfortunate locality. Therefore a miner, since we think he ought to be a good and serious man, should not make use of an enchanted twig, because if he is prudent and skilled in the natural signs, he understands that a forked stick is of no use to him, for as I have said before, there are natural indications of the veins which he can see for himself without the help of twigs.

## ENTROPY AND ICE CREAM

From "The Rise of the New Physics," Vol. I, by A. d'Abro

One of the most interesting applications of the principle of entropy (i.e. the principle that heat is irresistibly being lost in the universe—an increase in entropy means a decrease in available energy) is illustrated by the *Phase Rule*, discovered by Gibbs. It exemplifies that peculiar beauty which characterizes all of Gibbs' work.

A few definitions are necessary. A chemical substance, e.g., water, can exist under ordinary conditions in three different forms: the solid form (ice), the liquid form (water), and the vapor form (water vapor). These forms are called *phases*. Other substances, such as sulphur, exhibit a larger number of phases. Thus, under ordinary conditions sulphur can exist in the liquid or in the vapor phase or in two different crystalline forms constituting two different solid phases. Entropy considerations arise in changes of phase, as indeed in all physical changes. When a piece of ice melts, it absorbs heat energy. This heat energy is used up entirely to secure the passage from the solid to the liquid phase. No part of it serves to increase the temperature of the melting ice, which remains unchanged during the process of fusion. Let us call  $Q$  the quantity of heat absorbed by the ice during the fusion. If we

represent by  $T$  the constant temperature of the ice, the entropy acquired is  $\frac{Q}{T}$ . Thus, even though the temperature does not

change, entropy has been accumulated owing to the change in phase. Similar absorptions or rejections of entropy accompany all other changes of phase, such as evaporation and sublimation.

Another important notion is that of the *degrees of freedom* of a thermodynamical system. A given mass of gas in a given state has a definite volume, temperature, and pressure. But when any two of these three magnitudes are specified, the third is automatically determined. Since the state of the gas is defined by means of two independent magnitudes, we say, by analogy with the terminology of mechanics, that the gas system has two degrees of freedom.

With these preliminaries disposed of, we pass to the equilibrium of phases. Suppose we have a mixture of ice and water. The system is said to be in thermodynamical equilibrium if none of the ice melts into water, and if none of the water freezes into ice. Equilibrium is thus manifested by the absence of change. Obviously, a piece of ice placed in hot water does not represent a system in equilibrium.

Direct experiment has furnished considerable information on these equilibrium phenomena. As an example let us revert to the mixture of ice and water. Usually a mixture of this kind is in contact with the air and consequently with water vapor. To obviate the presence of the water vapor, we shall assume that the mixture fills a closed cylinder. If the temperature of the mixture is  $0^\circ$  Centigrade and the pressure one atmosphere, the ice and water are in thermodynamical equilibrium; the ice subsists and the water does not solidify. The slightest change, however, in the temperature or in the pressure will cause the equilibrium to be destroyed. For example, if we keep the temperature unchanged but increase the pressure by pushing against a piston, the ice will turn into water. The mixture is no longer in equilibrium. On the other hand, equilibrium will be restored under this increased pressure provided we lower the temperature by a suitable amount. Experiment shows more generally that at each definite pressure (within a certain range) there is a corresponding temperature of equilibrium for the ice and water. Conversely, if the temperature is specified, there is a corresponding equilibrium value for the pressure.

Next we examine the equilibrium of the two phases from the standpoint of the degrees of freedom. We have said that a gas has two degrees of freedom because both the pressure and the temperature of a given mass of gas can be prescribed at pleasure. On the other hand, if our mixture of ice and water is to be in

equilibrium, the temperature and the pressure cannot both be prescribed arbitrarily: the numerical value of only one of the two variables can be chosen freely; the value of the other variable is then determined by this choice. For this reason, we say that the system formed by a mixture of ice and water in equilibrium has but one degree of freedom. Other cases of equilibrium will be considered presently.

The conclusions which we have just stated follow from direct experiment and make no demands on any theoretical knowledge. But Gibbs, in his "phase rule," obtained a formula which determines the number of degrees of freedom of any system formed of one or more substances and phases in equilibrium. Gibbs' demonstration of his formula was based on the principle of entropy. We have seen that according to this principle, if any conceivable change which is compatible with the restrictions imposed on an isolated system would result in a decrease of the system's entropy, no change can occur, since a decrease in entropy means an increase in available energy—impossible in a closed system; the system will be in stable equilibrium. Even if, among the conceivable changes, some would leave the value of the entropy unaltered, spontaneous changes will still fail to appear. Consequently, the system is also in equilibrium in this case, but the equilibrium is now indifferent. The problem of determining under what conditions a system will be in thermodynamical equilibrium throws us back therefore on the problem of deciding under what conditions the entropy will be a maximum.

Guided by these considerations Gibbs established the following remarkable formula: He proved that, if a system formed of  $n$  different substances in  $k$  different phases is in a state of thermodynamical equilibrium, the number of degrees of freedom of the system in equilibrium is defined by

$$n - k + 2.$$

This is the celebrated phase rule.

As an example we revert to the mixture of ice and water. Here we have a single substance in two phases, and so we must set  $n = 1$  and  $k = 2$  in Gibbs' formula. The value of Gibbs'  $n - k + 2$  is then 1. We conclude that the system has one degree of freedom, a result already mentioned.

Next let us consider the equilibrium of three different phases of the same substance, e.g., ice, water, and water vapor. Here we have  $n = 1$  and  $k = 3$ , and Gibbs' formula yields zero for the degrees of freedom of the system. This means that neither the pressure nor the temperature can be assigned arbitrarily. There is but one specific pressure and one specific temperature at which all three phases can coexist in equilibrium.

If we assume one substance and four phases, Gibbs' formula

gives  $-1$  for the degrees of freedom. This result is meaningless, for the number of degrees of freedom cannot be negative. We conclude that, regardless of what the pressure and temperature may be, four different phases of the same substance (e.g., the four phases mentioned for sulphur) cannot possibly coexist in equilibrium. If, then, a recipient contains a substance in four different phases, we may expect one of the phases to be transformed gradually into the other three. The three remaining phases may then be in equilibrium at a certain temperature and pressure, as explained in the previous illustration.

Finally, we consider a system formed of two different substances in four phases. Here  $n = 2$  and  $k = 4$ , and Gibbs' rule yields zero for the number of degrees of freedom. Hence there is but one temperature and pressure at which all four phases can coexist (the temperature and the pressure of equilibrium). Suppose, then, the mixture is placed in a container. The system will pass of its own accord to the state of equilibrium, for this state corresponds to maximum entropy. The temperature of the mixture, therefore, moves automatically to the temperature of equilibrium.

As an illustration let us suppose that salt is sprinkled on ice. Some of the salt dissolves in the water adhering to the ice, and some of the salt persists in the solid phase. In addition, owing to evaporation, water vapor is formed. Altogether then we have two components (water and salt) and four phases; namely, ice, solid salt, solution of salt in water, and water vapor. The situation is the one we have just been discussing. Consequently, the mixture tends to assume automatically the temperature of equilibrium which experiment shows to be  $-22^\circ$  Centigrade. This lowering of the temperature is often utilized for refrigeration purposes; our mixture constitutes a "freezing mixture."

The great beauty of the phase rule, added to its importance in physics and in chemistry, has made it one of the most celebrated laws of theoretical physics.

## A BRIEF HISTORY OF VIVISECTION

From "An Introduction to the Study of Experimental Medicine,"  
by Claude Bernard

We are told that the kings of Persia delivered men condemned to death to their physicians, so that they might perform on them vivisections useful to science. According to Galen, Attalus III (Philometer), who reigned at Pergamon, one hundred thirty-seven years before Jesus Christ, experimented with poisons and antidotes on criminals condemned to death. Celsus recalls and approves the vivisection which Herophilus and Eristratus

performed on criminals with the Ptolemies' consent. It is not cruel, he says, to inflict on a few criminals, sufferings which may benefit multitudes of innocent people throughout all centuries. The Grand Duke of Tuscany had a criminal given over to a professor of anatomy, Fallopius, at Pisa, with permission to kill or dissect him at pleasure. As the criminal had a quartan fever, Fallopius wished to investigate the effects of opium on the paroxysms. He administered two drams of opium during an intermission; death occurred after the second experiment. Similar instances have occasionally recurred, and the story is well known of the archer of Meudon who was pardoned because a nephrotomy was successfully performed on him. Vivisection of animals also goes very far back. Galen may be considered its founder. He performed his experiments especially on monkeys and on young pigs and described the instruments and methods used in experimenting. Galen performed almost no other kind of experiments than that which we call disturbing experiments, which consisted of wounding, destroying or removing a part, so as to judge its function by the disturbance caused by its removal. He summarized earlier experiments and studied for himself the effects of destroying the spinal cord at different heights; of perforating the chest on one side or both sides at once; the effects of section of the nerves leading to the intercostal muscles and of section of the recurrent nerve. He tied arteries and performed experiments on the mechanism of deglutition.

## ON THE CONTRARY, MUCH DID HE THINK . . .

From "Non-Euclidean Geometry," by Roberto Bonola

As early as 1823 [Janos] Bolyai had grasped the real nature of his problem. His later editions only concerned the material and its formal expression. At that date he had already discovered the formula connecting the angle of parallelism with the line to which it corresponds—the equation that is the key to all Non-Euclidean Trigonometry. In the enthusiasm of discovery he wrote to his father, Wolfgang Bolyai, on November 3, 1823, "I have now resolved to publish a work on the theory of parallels, as soon as I shall have put the material in order, and my circumstances allow it . . . In the meantime I can say this: *I have created a new universe from nothing.* All that I have sent you till now is but a house of cards compared to the tower. I am as fully persuaded that it will bring me honor, as if I had already completed the discovery."

Wolfgang expressed the wish at once to add to his son's theory to the *Tentamen* since, "if you have really succeeded in the question, it is right that no time be lost in making it public, for two

reasons: first, because ideas pass easily from one to another, who can anticipate its publication; and secondly, there is some truth in this, that many things have an epoch, in which they are found at the same time in several places, just as the violets appear on every side in spring. Also every scientific struggle is just a serious war, in which I cannot say when peace will arrive. Thus we ought to conquer when we are able, since the advantage is always to the first comer."

Little did Wolfgang Bolyai think that his presentiment would correspond to an actual fact—that is, to the simultaneous discovery of Non-Euclidean Geometry by the work of Gauss, Taurinus, and Lobatschewsky.

## THE INCONVENIENT SIZE OF PLANCK'S CONSTANT

From "Matter and Light; The New Physics," by Louis de Broglie

Max Planck's brilliant intuition that light was not emitted continuously but rather in *quanta* or discrete bundles whose energies were proportional to the frequency of radiation,  $\nu$ , and equal to  $h\nu$ , where  $h$  is the universal constant since known as Planck's constant, provided the connecting link between the two camps into which Physics had been divided: the Physics of Matter and the Physics of Radiation.

Now, it is interesting to notice that if Planck's constant  $h$ , were infinitely small, the light-quanta having the value  $h\nu$  would also be infinitely small, and their number in a ray of given energy would be infinitely great. Everything would then occur as though the rays had a continuous structure, and were of that purely undulatory character which Fresnel and his school attributed to them. On the other hand, the material corpuscles could in such a case easily be proved to obey exactly the classical laws of the dynamics of the material point, and there would be no need whatever to introduce waves into the Theory of Matter. Hence, in other words, if the value of  $h$  were infinitely small, classical physics would be absolutely valid. But if, on the other hand, Planck's constant were infinitely great, then light-quanta would be enormous, and their existence would leap to the eye—if I may so put it—of the least attentive physicist. In this case, however, the material corpuscles would never again follow the laws of classical dynamics, and as soon as they began to be investigated at all it would be perceived that a wave must be introduced to predict their motion. Now in Nature, such as it actually is, the constant  $h$  is neither infinitely great nor infinitely small. Actually its value is finite, and from the human point of view it appears exceedingly small, since, expressed in centimeter-gramme-second

units it is given by the number  $6.55 \times 10^{-27}$ . Hence for the human observer, an infinitely small  $h$  is much nearer to the actually existing conditions than an infinitely great one; and this simple truth explains the real meaning of the recent developments in Physics. For we can now understand how it is that the Physics of yesterday was induced—after a rather cursory examination—to maintain that Light had a continuous structure and the character of a wave, while at the same time attributing to Matter a discontinuous structure and asserting that it was built up of corpuscles obeying the classical laws of dynamics. It required the far more ingenious and delicate experiments made by contemporary physicists to disclose the other aspects of the facts—I mean the discontinuous aspect of Light and the undulatory aspect of Matter.

### WHO IS THIS KROPOTKIN AND WHAT DOES HE WANT?

From "The Analysis of Matter," by Bertrand Russell

Although the new law of gravitation and the old do not lead to very different results—as, indeed, they could not, since the old law accorded closely with observed facts—yet the difference in the ideas involved is very great. A planet, in the new theory, is moving freely, whereas in the old theory it was subject to a central force directed towards the sun. In the old theory, the planet moved in an ellipse; in the new theory, it moves in the nearest possible approach to a straight line—to wit, a geodesic. In the old theory, the sun was like a despotic government, emitting decrees from the metropolis; in the new, the solar system is like the society of Kropotkin's dreams, in which everybody does what he prefers at each moment, and the result is perfect order. The odd thing is that, as far as observation goes, the difference between these two theories is exceedingly minute. To the plain man, it would seem impossible to reconcile the statement that the earth moves in an ellipse with the statement that it moves in a sort of straight line, however queer the sort may be. And yet almost the whole of the difference between these two statements is a matter of convention. It is possible to adhere to Euclidean space even now; this requires a different way of stating Einstein's law of gravitation, but does not demand the rejection of anything that has been proved true. . . .

However, we do well to adopt the Einsteinian interpretation: free particles move in geodesics, and the law of gravitation is a law as to how geodesics are shaped in the neighborhood of matter. This view is essentially simple, though it leads to complicated mathematics. It accords with the facts, and it puts the law of

gravitation in a recognizable place among physical principles, instead of leaving it, as heretofore, an isolated and unrelated law.

### A LONG STORY MADE SHORT

From "The Evolution of Scientific Thought, From Newton to Einstein," by A. d'Abro

To make a long story short, it was found by varying one of Euclid's fundamental assumptions, known as the Parallel Postulate, it was possible to construct two other geometrical doctrines, perfectly consistent in every respect, though differing widely from Euclidean geometry. These are known as the non-Euclidean geometries of Lobatchewski and of Riemann.

Euclid's parallel postulate can be expressed by stating that through a point in a plane it is always possible to trace one and only one straight line parallel to a given straight line lying in the plane. Lobatchewski denied this postulate and assumed that an indefinite number of non-intersecting straight lines could be drawn, and Riemann assumed that none could be drawn.

From this difference in the geometrical premises important variations followed. Thus, whereas in Euclidean geometry the sum of the angles of any triangle is always equal to two right angles, in non-Euclidean geometry the value of this sum varies with the size of the triangles. It is always less than two right angles in Lobatchewski's, and always greater in Riemann's. Again, in Euclidean geometry, similar figures of various sizes can exist; in non-Euclidean, this is impossible.

It appeared, then, that the universal absoluteness of truth formerly credited to Euclidean geometry would have to be shared by these two other geometrical doctrines. But truth, when divested of its absoluteness, loses much of its significance, so this co-presence of conflicting universal truths brought the realisation that a geometry was true only in relation to our more or less arbitrary choice of a system of geometrical postulates. From a purely rational point of view, there was no means of deciding which of several sets was true. The character of self-evidence which had been formerly credited to the Euclidean axioms was seen to be illusory.

The reason why the Euclidean axioms appeared self-evident was simply that they seemed to be proper mathematical abstractions derived from our experience with the light rays and material bodies among which we live. And to a first approximation, to be sure, the geometry of light rays and material bodies, is Euclidean. But we cannot prophesy what it may turn out to be when nature is studied with ever-increasing refinement. Furthermore, even were the geometry to be established for one definite region of



space, we could not assert that our idea of straightness, hence of geometry, might not vary from place to place and from time to time.

Such considerations might have appeared to be merely academic a few years ago; and non-Euclidean geometry, though of vast philosophical interest, might have seemed devoid of any practical importance. But today, thanks to Einstein, we have definite reasons for believing that ultra-precise observation of nature has revealed our natural geometry arrived at with solids and light rays to be slightly non-Euclidean and to vary from place to place. So although the non-Euclidean geometers never suspected it (with the exception of Gauss, Riemann and Clifford), our real world happens to be one of the dream-worlds whose possible existence their mathematical genius foresaw.

### THE CAPITAL OF KNOWLEDGE

(Quoted in "On Mathematics and Mathematicians,"  
by Robert Edouard Moritz.)

Who could have imagined, when Galvani observed the twitching of the frog muscles as he brought various metals in contact with them, that eighty years later Europe would be overspun with wires which transmit messages from Madrid to St. Petersburg with the rapidity of lightning, by means of the same principle whose first manifestations this anatomist then observed! . . .

He who seeks for immediate practical use in the pursuit of science, may be reasonably sure, that he will seek in vain. Complete knowledge and complete understanding of the action of forces of nature and of the mind, is the only thing that science can aim at. The individual investigator must find his reward in the joy of new discoveries, as new victories of thought over resisting matter, in the esthetic beauty which a well-ordered domain of knowledge affords, where all parts are intellectually related, where one thing evolves from another, and all show the marks of the mind's supremacy; he must find his reward in the consciousness of having contributed to the growing capital of knowledge on which depends the supremacy of man over the forces hostile to the spirit.

H. HELMHOLTZ

### WITH NERO, YOU NEVER CAN TELL

From "The Principles of Physical Optics," by Ernst Mach

It is a remarkable fact that the optical instruments—spectacles, the microscope, and the telescope—appeared *before* the

theoretical development of dioptrics. We must regard these inventions as the result of good fortune. The *necessity of understanding* and improving these devices caused the evolution of scientific dioptrics, which began with Kepler. Interest in these instruments was largely stimulated by the great discoveries of the astronomers (Galileo, Huygens, Cassini, and others) by means of the telescope, and of the anatomists (Leeuwenhock, Malpighi, Swammerdam, and others) by means of the microscope. Quite large branches of optics, such as Newton's theories of colour and dispersion, owe their origin primarily to this interest. Consequently we see here the beneficial effect of the mutual reaction of technique and science.

If however, it is now assumed that *accidental* experiences combined with *practical* interest can bring about various discoveries, there must first, indeed, have been suitable *objects* with which these fortunate observations could be made. Lenses or objects similar to lenses—to whatever purposes they may have been put—must have been in existence before the *telescope* could be discovered. This is an irrefutable postulate. In fact, this view is confirmed by historical investigations which undoubtedly establish the existence of such objects in classical times.

The concave mirror and its most striking characteristics were known to the ancients. Euclid was familiar with these, although he treated them in a faulty manner. The appearances to be seen with polished metal objects and the covers of vessels were too self-evident to escape observation. The knowledge of burning glasses is also referred to in various places. Strepsiades, in Aristophanes' "Clouds," refers to the annulling of a promissory note by burning off the letters with the help of a glass. We need not be surprised that the remarks of Pliny on such subjects are somewhat vague and strange, for he was by no means a critical author. We must not, however, assume that these remarks are wholly fabricated, for Pliny (Book 36, Chap. 67) says: "If one exposes to the sun, glass spheres filled with water they produce so much heat that one can set clothes on fire with it;" and (Book 37, Chap. 10): "I find that some physicians hold the view that there is nothing better for burning bodies than a glass sphere placed in the path of rays from the sun." With regard to Pliny's reference (Book 37, Chap. 16) to Nero's emerald, it is difficult to decide whether this served as a mirror or a lens for some other purpose.

### POINCARÉ'S PRIVATE WAR WITH THE PEANIANS

From "Science and Method," by Henri Poincaré

The symbolic language created by Signor Peano plays a very large part in the new researches of M. Couturat and Signor

Burali-Forti in their attempt to derive numbers from purely logical categories. It is capable of rendering some service, but it appears to me that M. Couturat attaches to it an exaggerated importance that must have astonished Peano himself. . . .

The essential element of this language consists in certain algebraical signs which represent the conjunctions: if, and, or, therefore. That these signs may be convenient is very possible, but that they should be destined to change the face of the whole philosophy is quite another matter. It is difficult to admit that the word *if* acquires, when written  $\supset$ , a virtue it did not possess when written *if*.

We may see this new method at work in a mathematical treatise by Signor Burali-Forti entitled "*Una Questione sui Numeri transfiniti*."

To begin with, we find that Signor Burali-Forti defines the number 1 in the following manner: —

$$1 = \iota T' \{Ko . (u, h) \in (u \in \text{One})\},$$

a definition eminently fitted to give an idea of the number 1 to people who had never heard it before.

I do not understand the Peanian well enough to venture to risk a criticism, but I am very much afraid that this definition contains a *petitio principii*, seeing that I notice the figure 1 in the first half and the word One in the second.

However that may be, Signor Burali-Forti starts with this definition, and, after a short calculation, arrives at the equation

$$(27) \quad 1 \in \text{No},$$

which teaches us that One is a number.

And since I am on the subject of these definitions of the first numbers, I may mention that M. Couturat has also defined both 0 and 1.

What is zero? It is the number of elements in the class nil. And what is the class nil? It is the class which contains none.

To define zero as nil and nil as none is really an abuse of the wealth of language, and so M. Couturat has introduced an improvement into his definition by writing

$$0 = \iota \Lambda : \phi x = \Lambda . \Lambda = (x \notin \phi x),$$

which means in English: zero is the number of the objects that satisfy a condition that is never fulfilled. But as never means *in no case*, I do not see that any very great progress has been made.

I hasten to add that the definition M. Couturat gives of the number 1 is more satisfactory.

One, he says in substance, is the number of elements of a class in which any two elements are identical.

It is more satisfactory, as I said, in this sense, that in order to

define 1, he does not use the word one; on the other hand, he does use the word two. But I am afraid that if we asked M. Couturat what two is, he would be obliged to use the word one.

## FROM THIS VALLEY THEY SAY YOU ARE GOING

From "Geographical Essays," by William Morris Davis

The so-called "valley" of the Red River of the North in Minnesota and Dakota is a broad plain of exceedingly level surface. It is so truly level that it illustrates the curvature of the earth in the same way that it is seen at sea; for in crossing the plain, first a distant tree-top is seen above the horizon, then a house-top, and at last the body of the house rises into full view, just as the upper and lower sails and the hull of the ship are brought into sight in sailing toward it on the ocean. This broad plain is a lake bottom, whence the water in which its fine sediments were laid down has been drained away, and drained away by so curious a process that if, in teaching modern history, it were noted that some existing form of government were as curiously related to the past, no teacher would hesitate to make reference to it. The northern barrier that held the waters of the lake was the southward front of a great sheet of ice that for a time obstructed the open northward drainage; and in the lake thus created, fine sediments were spread out so plentifully that they buried the former surface of the land, and so evenly that when the waters were drained away as the ice melted, a dead-level plain resulted.

The plain stands well above sea-level, and hence must suffer change as destructive processes attack it. Why, then, is it so smooth? Manifestly because it is young. There has not yet been time for streams to channel it. It is extremely immature, truly infantile in its appearance, with scarcely a sign of the variety of features that will be developed in its later history.

## THE GREEKS HAD THEIR PROBLEMS

From "History of Mathematics," by D. E. Smith

The Greeks very early found themselves confronted by three problems which they could not solve, at least by the use of the unmarked ruler and the compass alone.

The first was the trisection of any angle. The trisection of the right angle was found to be simple, but the trisection of any arbitrary angle whatever attracted the attention and baffled the efforts of many of their mathematicians. To this problem may be added the related ones of dividing any given angle into any required number of equal parts and of inscribing in a circle a



regular polygon of a given number of sides.

The second problem was the quadrature of the circle, that is, the finding of a square whose area is the same as that of a given circle. The solution would be simple if we could find a straight line that is equal in length to the circumference. This is easily accomplished by rolling the circle along a straight line, but such a proceeding makes use of an instrument other than the ruler and compasses, namely, of a cylinder with a marked surface.

The third problem was the duplication of a cube, that is, the finding of an edge of the cube whose volume is twice the volume of a given cube. This was known as the Delian Problem, one story of its origin being that the Athenians appealed to the oracle at Delos to know how to stay the plague which visited their city in 430 B.C. It is said that the oracle replied that they must double in size the altar of Apollo. This altar being a cube, the problem was that of its duplication. Since problems about the size and shape of altars appear in the early Hindu literature, it is not improbable that this one may have found its way, perhaps through Pythagoras, from the East. It was already familiar to the Greeks in the 5th century B.C., for we are told by Eratosthenes that Euripides (c. 485-406 B.C.) refers to it in one of his tragedies which is no longer extant.

### A PARABLE OF BURST WATER PIPES AND DIRTY PAINT

From "What is Science?" by Norman Campbell

It would seem that the explanations which, in the view of the man in the street, it is the business of science to offer, do not involve familiar ideas at all. Thus we may expect our scientific acquaintances to *explain* to us *why* our water-pipes burst during a frost or why paint becomes dirty sooner in a room lit by gas than in one lit by electricity. We shall be told in reply that the bursting of the pipes is due to the expansion of water when it is converted into ice, and the blackening of the paint to the combination of the white pigment with the sulphur present in coal-gas to form compounds that are dark, and not white, in colour. Now in these instances, the ideas involved in the explanation are probably less, and not more, familiar than those that they are used to explain. Many more people know that water-pipes burst during a frost than know that water (unlike most liquids) expands when it freezes; and many more know that their paint goes black than know that lead carbonate (one of the commonest white pigments) is converted by sulphur into black lead sulphide.

Why then do we regard our questions as answered? Why do we feel that, when we have received them, the matter is better

understood, and our ideas on it clearer and more satisfactory? The reason is that the events and changes have been explained by being shown to be particular examples of a general law. Water *always* expands when it freezes, although it does not always burst in household pipes; for it may not be contained in pipes or in any closed vessel. And lead carbonate *always* reacts with sulphur in the form present in coal-gas, even if it is not being used as a pigment. We feel that our experience is no longer peculiar and mysterious; it is only one instance of general and fundamental principles: It is one of the profoundest instincts of our intellectual nature to regard the more general principles as the more ultimately acceptable and satisfactory; it is this instinct which led men first to the studies that have developed into science.

### HOW CRUCIAL ARE CRUCIAL EXPERIMENTS?

From "The Study of the History of Science," by George Sarton

One calls a crucial experiment one which enables him to choose between hypotheses which are mutually exclusive by proving that one of them is right and that the other must be wrong. The classical example is that concerning the wave theory of light and the emission theory. There was much discussion in the first half of the nineteenth century as to which of those theories was right to the exclusion of the other. The latter had been favored by Newton and was generally accepted by the triumphant Newtonians; the first had been brilliantly but incompletely explained by Huygens, and after a century of neglect it had been revived by Young and almost completely vindicated by Fresnel. A few years after the latter's death, Sir William Rowan Hamilton in the course of his analytical development of the wave theory was able to predict the existence of a rare kind of refraction, the conical refraction, which had never been observed. Hamilton's mathematical prediction of 1832 was verified experimentally by Humphrey Lloyd in the following year. The wave theory seemed to be established on an inexpugnable basis, and yet some of the defenders of the emission theory refused to capitulate. It was then that Arago invented an ingenious *experimentum crucis*. If the emission theory is correct, the speed of light must increase with the density of the medium; if the wave theory is correct, the speed must decrease with the density. Hence if we could measure the speed of light in air and water, the comparison of the results would tell us which theory was true. The extremely delicate experiments which he suggested were not realized until fifteen years later by Foucault, who proved that the speed of light is smaller in water than in air, and thus "that the emission theory is incompatible with the reality of the facts" (these are his own words).

This seemed to be decisive and final. There is no doubt that the emission theory was incompatible with the facts which he dealt with, but it did not follow that the wave theory was compatible with every other fact. To make a long story short, the study of the black-body radiation revealed facts which were incompatible with the wave theory, and led to the formulation of the quantum theory by Max Planck in 1900. Arago's *experimentum crucis* had simply proved that the wave theory was more complete than the emission theory, but it had not proved and could not prove that it was absolutely true.

It is clear that no experiment can be really 'crucial' until we are sure that our analysis of the possibilities is exhaustive, and this implies an omniscience which is hardly within our reach. Does this mean that the so-called crucial experiments are futile? Far from it: they enable us to continue further (if not to complete) the logical analysis of a set of problems, and incidentally to study the development of competitive theories and reactions to them of different minds. The story of the Arago-Foucault experiments will always be one of the most beautiful in the history of mankind.

### A PROBLEM FOR ZOOLOGISTS, BUT NOT FOR FROGS

From "The Biology of the Amphibia," by G. Kingsley Noble

It is frequently difficult for the collector to distinguish the sexes of Amphibia in the field. How do the breeding males distinguish the females from their own sex? Females come to the breeding grounds attracted in part by the call of the male. In the case of tree toads, the female may even follow the voice until she strikes the male's body. Most male frogs and toads seize any object of about their own size moving near them; a tree toad, when touched by the female, turns and embraces her. Nevertheless, no male frog recognizes the female as a sexual object. If the object embraced possesses certain qualities it is retained until the time of egg laying. The first requirement of the Wood Frog, *Rana sylvatica*, is a wide girth and resistance to compression. Male Wood Frogs injected with water until they had the same firmness as a female with eggs were seized and retained as long as females. A second requirement in the Wood Frog, and especially the common toad, is silence. The male frog, when embraced by another, croaks, the female remains silent. This differential action has been claimed to be the sole basis of sex recognition, since males were supposed to disdain an embraced partner which croaked. Male toads do not croak but chirp when seized. There can be little doubt that the warning croak or chirp is one of the factors in

sex recognition in some frogs and toads, although Hinsche failed to find evidence of it in the European toad, *Bufo vulgaris*.

The factors permitting sex recognition in frogs and toads would seem, then, to vary with the species, but in all cases there would seem to be more than one. In addition to body size and silence there is clearly an agitation factor in some forms. Hinsche obtained evidence that it was the vibration of the flanks of the female *Bufo vulgaris* and the jolting movements of her locomotion which were chiefly responsible for the male retaining his grip. The skin of the female *B. vulgaris* is rougher than that of the male, and Hinsche found that smooth, hard objects induce a failure of the clasping reflex. Males would also not be held by the males, because during the breeding season they change their gait to a hop which makes that sex difficult to catch. There are thus various factors both before and after the embrace which insure that females will be seized instead of males and that they will be held until the time of fertilization.

### DID LIFE ON EARTH COME FROM OUTER SPACE?

From "The Origin of Life," by A. I. Oparin

Modern astronomical conceptions offer no support to the idea of a ubiquitous distribution of life germs throughout the universe. Of course, this does not mean that life exists only on our Earth. We still have too little information to deny completely the possibility of existence of organisms on some other planets, whirling around stars similar to our Sun. But there can be no doubt that these worlds inhabited by living organisms are much farther removed from our solar system than are the nearest stars. Therefore, the transport of living germs from one planetary system to another would require not thousands of years, as Arrhenius thought, but at least many hundreds of thousands or even millions of years.

These long periods alone would make transport of viable germs extremely improbable. But the investigations of the last years on short wave interstellar radiations remove such a possibility completely. The lethal action of light rays of short wave length, particularly the ultraviolet rays, on microorganisms and their spores has long been known. Frequently, even a brief radiation is sufficient to sterilize completely a given medium and to destroy all the microorganisms and spores. The light of the stars is rich in ultraviolet rays but the atmosphere around our Earth protects us from their destructive effect. Life germs carried beyond the limit of this atmosphere would be inevitably killed off by the ultraviolet radiation penetrating the interstellar spaces.

The believers in the theory of panspermia attempted to ward

off this objection [by pointing out certain conditions under which ultraviolet rays are not lethal]. . . . But these [attempts] can be entirely neglected nowadays since the discovery of the very short rays of cosmic radiation. These rays have much shorter wave lengths than the ultraviolet . . . rays . . . and the changes brought about under their action are no longer purely chemical, but much more far-reaching intra-atomic changes. . . .

Life germs wayfaring in the interstellar space unprotected against cosmic radiation would not only be absolutely doomed to perish, but even their inner chemical structure would in a comparatively short time suffer radical changes under the influence of radiant energy. We must, therefore, once and for all give up the idea that life germs floated towards our Earth from outside cosmic spaces. We must, instead, search for the sources of life within the boundaries of our own planet.

### BRITISH FOGS AND WILSON CHAMBERS

From "The Restless Universe," by Max Born

The Wilson Cloud Chamber banished the last doubt that matter consisted of very fine particles, by making the tracks of these particles visible. It is really no wonder that this was invented in a country like Great Britain, where thick fog is so frequent and troublesome a phenomenon. Why are London and Manchester foggier—and dirtier—cities than Berlin and Munich? Yes, dirtier too; for fog and dirt go together. The reason is the British love for the open coal fire with its incomplete combustion. Innumerable chimneys vomit forth soot day after day, and soot gives rise to fog.

The connexion between them is this: air can mix with water vapour but not in any quantities. There is a maximum of humidity; we then say that the air is saturated with water vapour. This point depends on the height of the barometer, i.e. the pressure of the atmosphere. If the barometer suddenly falls, the quantity of water which the air can retain, as vapour, falls, and the surplus condenses into droplets.

If, however, the pressure is lowered cautiously and the air is pure, condensation can be avoided. There is indeed more water vapour than the air can really hold, but the formation of droplets does not occur—in a sense because the water molecules do not know where to begin lumping themselves together. This task is made easier for them, however, if there is any dust or soot floating in the air. At once the water molecules rush to the surface of these granules, cover them, and speedily form droplets with a nucleus of soot. There you have your fog! And down it sinks, covering everything with a greasy black layer of soot.

In Berlin and Munich, where the coal is burned thoroughly in central-heating plants, the air remains clearer and purer; on the other hand, the comfort of the crackling open coal fire is not known there.

Now it has been found that not only dust and soot, but also charged molecules (ions) form excellent nuclei for drops to form on. The electric forces radiating from the ion obviously attract the water molecules.

This fact is utilized in the Wilson Chamber to make the paths of particles visible. We have a chamber full of air saturated with water vapour, closed by a piston. If the piston is suddenly pulled out, lowering the pressure in the chamber, the vapour is super-saturated, but remains for a short time in that state, as there are no dust particles present to act as nuclei for droplet formation. If we now shoot particles into the chamber (for example, by placing a bit of radioactive material in the chamber) these form pairs of ions along their path, which act as condensation nuclei and collect a layer of water droplets on their surfaces; the paths of the particles are rendered visible as fine tracks of fog!

### AN OBSERVATION OF CONSIDERABLE MAGNITUDE

From "The Realm of the Nebulae," by Edwin Hubble

The Cepheids are pulsating stars which brighten rapidly and fade slowly, repeating the cycle continuously and faithfully. The period (length of the cycle) is constant for an individual star, but varies from one star to another, ranging from about one day to a hundred days. The range in luminosity is also constant for a given star, but varies within the group from about 0.8 to 2.0 magnitudes. From these features the Cepheids are easily recognized wherever they may be found.

Several dozen are known among the stars in the galactic system, but they are scattered at wide intervals and even the nearest is very remote from the earth. For this reason the determination of distances, and hence absolute magnitudes, has been a difficult problem. Before it was completely solved, a new feature, of extraordinary significance, was discovered among the Cepheids in the small Magellanic Cloud.

The Cloud is an independent stellar system and a close neighbor—actually a satellite—of the galactic system. It offers a unique opportunity to study a sample collection of stars which are all at about the same distance from the observer. It is so remote that only the brighter stars (giants and supergiants) can be observed.

Investigations of the Cloud, made at the Harvard College Ob-

servatory, led to the discovery of several hundred variable stars. Some were carefully followed and most of these were identified as Cepheids. As early as 1908, Miss Leavitt, who made the investigations, remarked that the brightest Cepheids had longer periods (pulsated more slowly) than the fainter Cepheids. In 1912, she announced a definite period-luminosity relation. The logarithms of the periods increased directly with the median magnitudes (the mid-points between maxima and minima). Thus, if the period of any Cepheid in the Cloud was known, the apparent magnitude was determined. The relation evidently reflected certain inherent characteristics of Cepheids which would presumably be found in all such stars wherever they might be located—in the Cloud, in the galactic system, or elsewhere. If the relation could be numerically calibrated—if the *absolute* magnitude i.e. the intrinsic luminosity, how bright the star actually is—for any one period could be established—the Cepheids, since they are so readily identified, would furnish a powerful method of estimating great distances since a simple calculation of the relation of the apparent magnitude to the absolute magnitude gives the distance.

Hertzprung, who immediately recognized the full significance of the period-luminosity relation, made the first calibration in 1913. He determined the mean distance of thirteen galactic Cepheids from their parallax motions (reflections of the motion of the sun among the stars). The individual distances were very uncertain, but the mean for the group was fairly reliable and furnished a mean absolute magnitude corresponding to a particular mean period. These data permitted him to calibrate the period-luminosity relation, make a provisional estimate of the distance of the Cloud, and examine the distribution of Cepheids in the galactic system.

Five years later (1918) Shapley repeated the calculations and materially revised the calibration. Later alterations, introduced by Shapley, led to the current form of the period luminosity relation. Further revision is expected to be of minor importance. Thus, wherever a Cepheid may be found, the period will indicate the absolute luminosity, and the apparent faintness then measures the distance. It was by this method that the first reliable distances of nebulae were determined.

## THE DEATH OF THE TACOMA NARROWS

From "Bridges and Their Builders," by David B. Steinman and Sara Ruth Watson

The Tacoma Narrows Bridge was by far the most flexible of all modern suspension bridges. . . . It looked like a slender ribbon from bank to bank. This lateral flexibility of the bridge, however,

was not a factor in the failure. Although the bridge was calculated to have a theoretical maximum lateral deflection of twenty-one feet at full wind pressure, its actual maximum lateral deflection at mid-span never exceeded four feet, even during the gale which destroyed it.

What proved critical, however, was the vertical slenderness of the span. A generation earlier, authorities had recommended for the stiffening trusses of suspension bridges a minimum depth of one fortieth of the span. . . . The stiffening girders of the Tacoma Bridge were made only 8 feet deep in a span of 2,800 feet, or only one three-hundred-and-fiftieth of the span!

The other factor was the newly discovered phenomenon called aerodynamic instability. The Tacoma Bridge had solid web plate girders, and when a solid bridge floor is framed into the solid webs of such plate girders, the resulting cross-section is peculiarly sensitive to aerodynamic effects, even in a steady wind, particularly if the span is highly flexible. . . .

From about 7 A. M. on the morning of November 7, 1940, the bridge had been persistently undulating for some three hours. A wind of thirty-five to forty-two miles per hour was blowing, and the waters of Puget Sound were whipped into whitecaps. The segments of the span were heaving periodically up and down as much as three feet, with a frequency of about thirty-six cycles per minute. Alarmed at the persistent character of the wave motion in the span, the highway authorities stopped traffic over the structure. At 10 A. M., the last truck was passing over the span, when something seemed to snap, and, suddenly, the character of the motion changed. The rhythmic rise and fall changed to a two-wave twisting motion, with the two sides out of phase. The main span was oscillating into two segments, with nodes at mid-span. As two diagonally opposite quarter-points were going up, the other two diagonally opposite quarter-points were going down. The frequency was fourteen cycles per minute and, soon after, changed to twelve cycles per minute. With each successive cycle, the motion was becoming greater, until it had increased from three feet to twenty-eight feet! At one moment, one edge of the roadway was twenty-eight feet higher than the other; the next moment it was twenty-eight feet lower than the other edge. The roadway was tilted forty-five degrees from the horizontal one way, and then forty-five degrees the other way. Lamp standards in one half of the span made an angle of ninety degrees with lamp standards in the other half. Fortunately, some amateur photographers were at the scene with motion picture cameras, and they have supplied us with a unique and unprecedented record of the action of the span in its dance of death. The motion pictures of the twisting span are unforgettable, and the distortions they depict, in character and magnitude, are almost unbelievable.



The span twists in gigantic waves, and it is difficult to realize that the girders were made, not of rubber, but of structural steel having a modulus of elasticity of 29,000,000 pounds per square inch. For a half hour and more, the steelwork and concrete slab took this terrific punishment. Something was bound to give way. At 10:30 came the first break: one floor panel at mid-span broke out and dropped into the water 208 feet below. The twisting, writhing motion continued. Spectators on the shore were herded to a safer distance away from the span. At 11 A. M. the real breaking up of the span occurred: 600 feet of the main span near the west quarter-point tore away from the suspenders, the girders ripping away from the floor like a zipper; part of the falling bridge floor turned upside down before the entire falling mass hit the water, sending up spray to a great height. With a 600-foot section of the bridge gone, the engineers of the bridge structure expected the motion to subside. But the heaving and twisting of the rest of the bridge continued, with the side spans now participating in the motions. Finally, at 11:00 A. M., nearly all the rest of the main span tore loose and came crashing down. The 1,100-foot side spans, now deprived of the counterbalancing weight of the main span, suddenly deflected about 60 feet, striking the approach parapet; then bounced up with an elastic rebound, only to drop again with a final sag of about 30 feet. This was the final gigantic convulsion in the death struggle of a great bridge.

## VULGAR PEOPLE AND PEACOCK'S FEATHERS

From "Opticks," by Sir Isaac Newton

*Exper. 5.* Now, that these Colours [i.e. the colours of the spectrum produced by refracting sunlight through a prism] could not be changed by [further] Refraction, I knew by refracting with a Prism sometimes one very little Part of this Light, sometimes another very little Part. . . . For by this Refraction the Colour of the Light was never changed in the least. If any Part of the red Light was refracted, it remained totally of the same red Colour as before. No orange, no yellow, no green or blue, no other new Colour was produced by that Refraction. Neither did the Colour any ways change by repeated Refractions, but continued always the same red entirely as at first. The like Constancy and Immutability I found also in the blue, green, and other Colours. So also, if I looked through a Prism upon any Body illuminated with any part of this homogeneous Light . . . I could not perceive any new Colour generated this way. All Bodies illuminated with compound Light appear through Prisms confused . . . and tinged with various new Colours, but those illuminated with homogeneous Light appeared through Prisms

neither less distinct, nor otherwise colour'd, than when viewed with the naked Eyes. Their Colours were not in the least changed by Refraction of the interposed Prisms. . . .

*Exper. 6.* And as these Colours were not changeable by Refractions, so neither were they by Reflexions. For all white, grey, red, yellow, green, blue, 'violet Bodies, as Paper, Ashes, red Lead, Orpiment, Indico Bise, Gold, Silver, Copper, Grass, blue Flowers, Violets, Bubbles of Water tinged with various Colours, Peacock's Feathers, the Tincture of *Lignum Nephriticum*, and such-like, in red homogeneous Light appeared totally red, in blue Light totally blue, in green Light totally green, and so of other Colours. In the homogeneous Light of any Colour they all appeared totally of that same Colour, with this only Difference, that some of them reflected that Light more strongly, others more faintly. I never yet found any Body, which by reflecting homogeneous Light could sensibly change its Colour.

From all which it is manifest, that if the Sun's Light consisted of but one sort of Rays, there would be but one Colour in the whole World, nor would it be possible to produce any new Colour by Reflexions and Refractions, and by consequence that the variety of Colours depends upon the Composition of Light.

*Definition.* The homogeneous Light and Rays which appear red, or rather make Objects appear so, I call Rubrifick or Red-making; those which make Objects appear yellow, green, blue, and violet, I call Yellow-making, Green-making, Blue-making, Violet-making, and so of the rest. And if at any time I speak of Light and Rays as coloured or endued with Colours, I would be understood to speak not philosophically and properly, but grossly, and accordingly to such Conceptions as vulgar People in seeing all these Experiments would be apt to frame. For the Rays to speak properly are not coloured. In them there is nothing else than a certain Power and Disposition to stir up a Sensation of this or that Colour. For as Sound in a Bell or musical String or other sounding Body, is nothing but a trembling Motion, and in the Air nothing but that Motion propagated from the Object, and in the Sensorium 'tis a Sense of that Motion under the Form of Sound; so Colours in the Object are nothing but a Disposition to reflect this or that sort of Rays more copiously than the rest; in the Rays they are nothing but their Dispositions to propagate this or that Motion into the Sensorium, and in the Sensorium they are Sensations of those Motions under the Forms of Colours.

## ARISTOTLE TOPPLES

From "Dialogues Concerning Two New Sciences," by Galileo Galilei

*SALV.\** I greatly doubt that Aristotle ever tested by experiment whether it be true that two stones, one weighing ten times

\* Salv. = Salviati; Simp. = Simplicio; Sagr. = Sagredo.

as much as the other, if allowed to fall, at the same instant, from a height of, say, 100 cubits, would so differ in speed that when the heavier had reached the ground, the other would not have fallen more than 10 cubits.

SIMP. His language would seem to indicate that he had tried the experiment, because he says: *We see the heavier*; now the word *see* shows that he had made the experiment.

SAGR. But I, Simplicio, who have made the test can assure you that a cannon ball weighing one or two hundred pounds, or even more, will not reach the ground by as much as a span ahead of a musket ball weighing only half a pound, provided both are dropped from a height of 200 cubits.

SALV. But, even without further experiment, it is possible to prove clearly, by means of a short and conclusive argument, that a heavier body does not move more rapidly than a lighter one provided both bodies are of the same material and in short such as those mentioned by Aristotle. But tell me, Simplicio, whether you admit that each falling body acquires a definite speed fixed by nature, a velocity which cannot be increased or diminished except by the use of force [*violenza*] or resistance.

SIMP. There can be no doubt but that one and the same body moving in a single medium has a fixed velocity which is determined by nature and which cannot be increased except by the addition of momentum [*impeto*] or diminished except by some resistance which retards it.

SALV. If then we take two bodies whose natural speeds are different, it is clear that on uniting the two, the more rapid one will be partly retarded by the slower, and the slower will be somewhat hastened by the swifter. Do you not agree with me in this opinion?

SIMP. You are unquestionably right.

SALV. But if this is true, and if a large stone moves with a speed of, say, eight while a smaller moves with a speed of four, then when they are united, the system will move with a speed less than eight; but the two stones when tied together make a stone larger than that which before moved with a speed of eight. Hence the heavier body moves with less speed than the lighter; an effect which is contrary to your supposition. Thus you see how, from your assumption that the heavier body moves more rapidly than the lighter one, I infer that the heavier body moves more slowly.

SIMP. I am all at sea because it appears to me that the smaller stone when added to the larger increases its weight and by adding weight I do not see how it can fail to increase its speed or, at least, not to diminish it.

SALV. Here again you are in error, Simplicio, because it is not true that the smaller stone adds weight to the larger.

SIMP. This is, indeed, quite beyond my comprehension.

SALV. It will not be beyond you when I have once shown you the mistake under which you are laboring. Note that it is necessary to distinguish between heavy bodies in motion and the same bodies at rest. A large stone placed in a balance not only acquires additional weight by having another stone placed upon it, but even by the addition of a handful of hemp its weight is augmented six to ten ounces according to the quantity of hemp. But if you tie the hemp to the stone and allow them to fall freely from some height, do you believe that the hemp will press down upon the stone and thus accelerate its motion or do you think the motion will be retarded by a partial upward pressure? One always feels the pressure upon his shoulders when he prevents the motion of a load resting upon him; but if one descends just as rapidly as the load would fall how can it gravitate or press upon him? Do you not see that this would be the same as trying to strike a man with a lance when he is running away from you with a speed which is equal to, or even greater, than that with which you are following him? You must therefore conclude that, during free and natural fall, the small stone does not press upon the larger and consequently does not increase its weight as it does when at rest.

SIMP. But what if we should place the larger stone upon the smaller?

SALV. Its weight would be increased if the larger stone moved more rapidly; but we have already concluded that when the small stone moves more slowly it retards to some extent the speed of the larger, so that the combination of the two, which is a heavier body than the larger of the two stones, would move less rapidly, a conclusion which is contrary to your hypothesis. We infer therefore that large and small bodies move with the same speed provided they are of the same specific gravity.

SIMP. Your discussion is really admirable; yet I do not find it easy to believe that a bird-shot falls as swiftly as a cannon ball.

SALV. Why not say a grain of sand as rapidly as a grindstone? But, Simplicio, I trust you will not follow the example of many others who divert the discussion from its main intent and fasten upon some statement of mine which lacks a hair's-breadth of the truth and, under this hair, hide the fault of another which is as big as a ship's cable. Aristotle says that "an iron ball of one hundred pounds falling from a height of one hundred cubits reaches the ground before a one-pound ball has fallen a single cubit." I say that they arrive at the same time. You find, on making the experiment, that the larger outstrips the smaller by two finger-breadths, that is, when the larger has reached the ground, the other is short of it by two finger-breadths; now you would not hide behind these two fingers the ninety-nine cubits of Aristotle, nor would you mention my small error at the same time to pass over in silence his very large one. Aristotle declares



that bodies of different weights, in the same medium, travel (in so far as their motion depends upon gravity) with speeds which are proportional to their weights; this he illustrates by use of bodies in which it is possible to perceive the pure and unadulterated effect of gravity, eliminating other considerations, for example, figure as being of small importance [*minimi momenti*], influences which are greatly dependent upon the medium which modifies the single effect of gravity alone. Thus we observe that gold, the densest of all substances, when beaten out into a very thin leaf, goes floating through the air; the same thing happens with stone when ground into a very fine powder. But if you wish to maintain the general proposition you will have to show that the same ratio of speeds is preserved in the case of all heavy bodies, and that a stone of twenty pounds moves ten times as rapidly as one of two; but I claim that this is false and that, if they fall from a height of fifty or a hundred cubits, they will reach the earth at the same moment.

SIMP. Perhaps the result would be different if the fall took place not from a few cubits but from some thousands of cubits.

SALV. If this were what Aristotle meant you would burden him with another error which would amount to a falsehood; because, since there is no such sheer height available on earth, it is clear that Aristotle could not have made the experiment; yet he wishes to give us the impression of his having performed it when he speaks of such an effect as one which we see.

### ANYONE YOU KNOW?

From "Fads and Fallacies in the Name of Science,"  
by Martin Gardner

There are five ways in which the sincere pseudo-scientist's paranoid tendencies are likely to be exhibited.

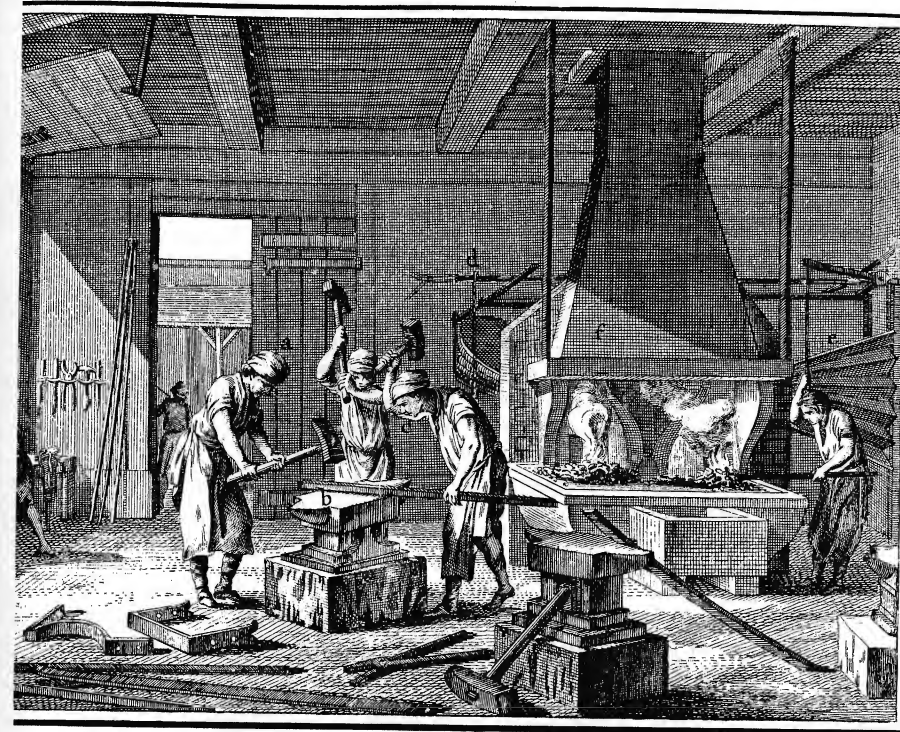
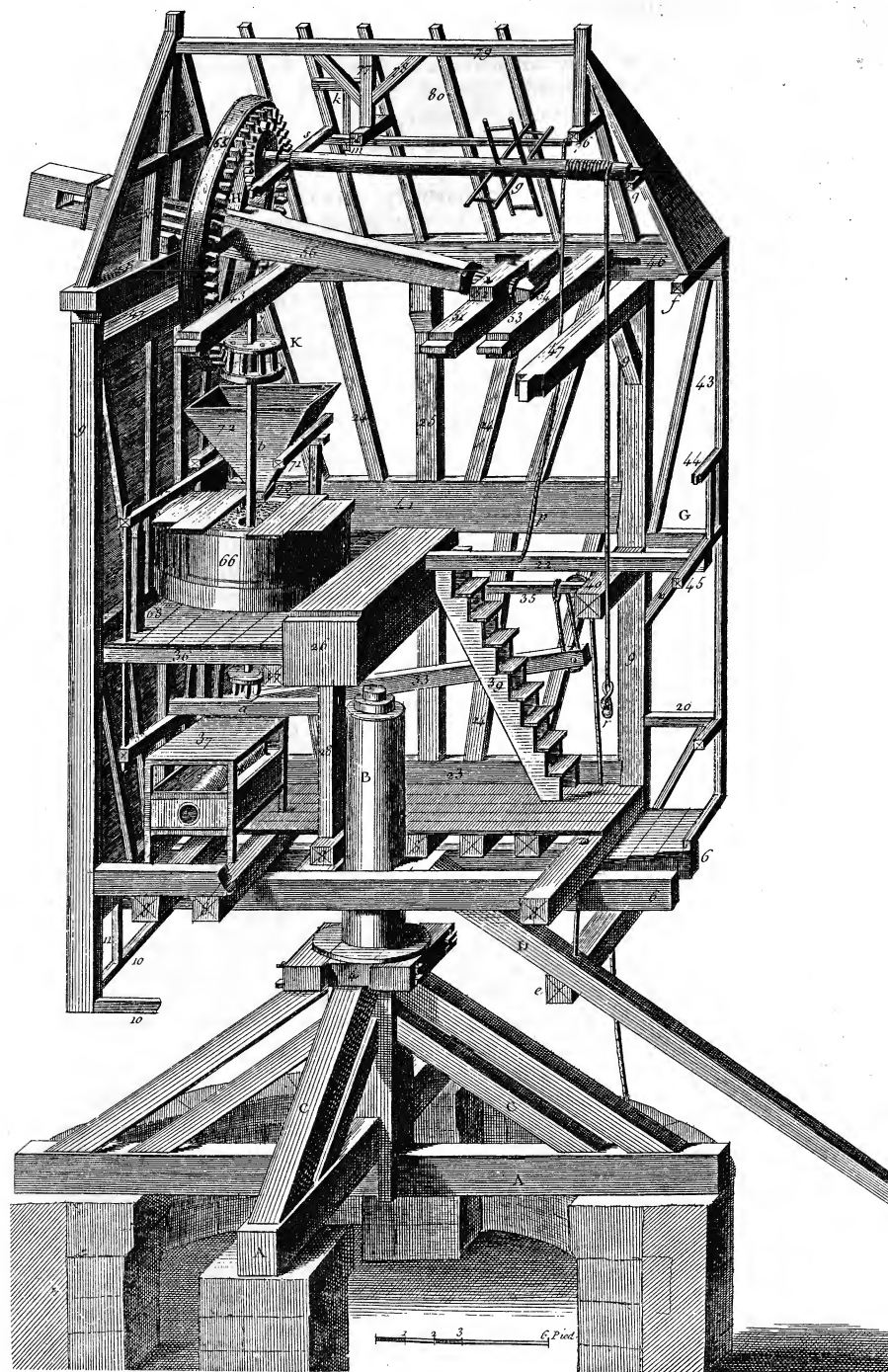
- (1) He considers himself a genius.
- (2) He regards his colleagues, without exception, as ignorant blockheads. Everyone is out of step except himself. Frequently he insults his opponents by accusing them of stupidity, dishonesty, or other base motives. If they ignore him, he takes this to mean his arguments are unanswerable. If they retaliate in kind, this strengthens his delusion that he is battling scoundrels.
- (3) He believes himself unjustly persecuted and discriminated against. The recognized societies refuse to let him lecture. The journals reject his papers and either ignore his books or assign them to "enemies" for review. It is all part of a dastardly plot. It never occurs to the crank that this opposition may be due to error in his work. It springs solely, he is convinced, from blind prejudice on the part of the established hierarchy—the high priests of science who fear to have their orthodoxy overthrown.

Vicious slanders and unprovoked attacks, he usually insists, are constantly being made against him. He likens himself to Bruno, Galileo, Copernicus, Pasteur, and other great men who were unjustly persecuted for their heresies. If he has had no formal training in the field in which he works, he will attribute this persecution to a scientific masonry, unwilling to admit to its inner sanctums anyone who has not gone through the proper initiation rituals. He repeatedly calls your attention to important scientific discoveries made by laymen.

(4) He has strong compulsions to focus his attacks on the greatest scientists and the best-established theories. When Newton was the outstanding name in physics, eccentric works in that science were violently anti-Newton. Today, with Einstein the father-symbol of authority, a crank theory of physics is likely to attack Einstein in the name of Newton. This same defiance can be seen in a tendency to assert the diametrical opposite of well-established beliefs. Mathematicians prove the angle cannot be trisected. So the crank trisects it. A perpetual machine cannot be built. He builds one. There are many eccentric theories in which the "pull" of gravity is replaced by a "push." Germs do not cause disease, some modern cranks insist. Disease produces the germs. Glasses do not help the eyes. They make them worse.

(5) He often has a tendency to write in a complex jargon, in many cases making use of terms and phrases he himself has coined. Schizophrenics sometimes talk in what psychiatrists call "neologisms"—words which have meaning to the patient, but sound like Jabberwocky to everyone else. Many of the classics of crackpot science exhibit a neologistic tendency.

When the crank's I.Q. is low, he rarely achieves much of a following. But if he is a brilliant thinker, he is capable of developing incredibly complex theories. He will be able to defend them in books of vast erudition, with profound observations, and often liberal portions of sound science. His rhetoric may be enormously persuasive. All the parts of his world usually fit together beautifully, like a jig-saw puzzle. It is impossible to get the best of him in any type of argument. He has anticipated all your objections. He counters them with unexpected answers of great ingenuity. Even on the subject of the shape of the earth, a layman may find himself powerless in a debate with a flat-earth. George Bernard Shaw, in *Everybody's Political What's What?*, gives an hilarious description of a meeting at which a flat-earth speaker completely silenced all opponents who raised objections from the floor. "Opposition such as no atheist could have provoked assailed him, . . ." writes Shaw, "and he, having heard their arguments hundreds of times, played skittles with them, lashing the meeting into a spluttering fury as he answered easily what it considered unanswerable."



### DIDEROT PICTORIAL ENCYCLOPEDIA

*Right hand page. A view of an 18th century ironworker's shop. In the 18th century, structural iron played a relatively minor role. By far the greatest uses of iron were ornamental and incidental. Ironworkers were skilled artisans who filled orders for such varied products as elaborate ornamental grillwork, window-bars, hinges, angle-irons, down-spouts, and the curved spike fences which are still seen on the roofs of Paris.*

*Left hand page. The internal construction of an 18th century windmill. Before the Industrial Revolution, power was a rural product, drawn directly from nature. This is a post mill which can be revolved into the wind for maximum efficiency. Grain is fed through the inverted pyramidal hopper into the stone millwheel directly below. The entire construction indicates a very high order of mechanical ingenuity.*

These are Plates 165 and 17 in *A Diderot Encyclopedia of Trades and Industry*, edited by Charles Coulston Gillispie of Princeton University. The 485 plates in this two-volume set were selected from the famous *Encyclopédie, ou Dictionnaire Raisonné des Sciences, des Arts et des Métiers*, of Denis Diderot. Considered among the finest examples of 18th-century copperplate engraving, they also form the most extensive pictorial record of pre-industrial revolution trades and industries in existence.

## IS NO ONE SAFE FROM MATHEMATICIANS?

Quoted in "On Mathematics and Mathematicians,"  
by Robert Edouard Moritz

Euler was a believer in God, downright and straightforward. The following story is told by Thiebault, in his "Souvenirs de vingt ans de séjour à Berlin". . . . Thiebault says that he has no personal knowledge of the truth of the story, but that it was believed throughout the whole of the north of Europe. Diderot paid a visit to the Russian Court at the invitation of the Empress. He conversed very freely, and gave the younger members of the Court circle a good deal of lively atheism. The Empress was much amused, but some of her counselors suggested that it might be desirable to check these expositions of doctrine. The Empress did not like to put a direct muzzle on her guest's tongue, so the following plot was contrived. Diderot was informed that a learned mathematician was in possession of an algebraical demonstration of the existence of God, and would give it before all the Court, if he desired to hear it. Diderot gladly consented: though the name of the mathematician is not given, it was Euler. He advanced toward Diderot, and said gravely, and in a tone of perfect conviction:

Monsieur,  $\frac{a+b^n}{n} = x$ , donc Dieu existe; répondez!

Diderot, to whom algebra was Hebrew, was embarrassed and disconcerted; while peals of laughter rose on all sides. He asked permission to return to France at once, which was granted.

ON THE OTHER HAND,  
IT MIGHT HAPPEN TOMORROW

From "The Nature of Physical Theory," by P. W. Bridgman

It is usual in discussing the deductions of the second law of thermodynamics or of the meaning of entropy from the statistical point of view to emphasize that on the basis of statistical mechanics unfamiliar configurations of a system are not impossible, but only improbable. One may even compute how many years one may have to wait to see a pail of water freeze on the fire. What physical meaning shall we give to the result of this calculation? The result is of course such a large number of years as to forever discourage any thought of a direct experimental verification; we content ourselves with a very rough and qualitative check on the plausibility of our result by remarking that

such an event has never been observed to occur, and that our calculation shows that in all the time of past recorded observations such an event would have been exceedingly improbable. The improbability is so high, however, that we can accept the merely negative results of observation as lending only a very weak plausibility of the "truth" of the calculation. The meaning of the "truth" of such a calculation must be sought in other directions. If we could show that the conclusion followed necessarily by logical processes from the assumptions that went into the deduction, and if we could show that the assumptions were true physically by some sort of operational test, then I think we would be willing to call the conclusion "true." Among the assumptions that went into the deduction were the laws of mechanics. It can be shown that these would have to hold with a very high degree of precision indeed, a precision fantastically beyond any possible experimental verification, in order to demand the conclusion. Hence we are not justified in saying that our mathematical theory requires us to believe that the freezing of a pail of water on the fire at rare intervals is a necessary feature of our universe.

## IS THE EARTH HEATING UP?

From "The Evolution of Igneous Rocks," by N. L. Bowen

The temperatures that may exist at various depths within the earth present a very difficult problem. We have evidence from man-made sections of a continuous rise of temperature which varies considerably from place to place. The actual depth which these sections attain is utterly insignificant and while extrapolation of the temperature curve would rapidly carry us to very high temperatures, the real evidence of the existence of high temperatures anywhere in the earth comes from the fact that, at frequent intervals in the earth's history, rocks which are molten only above 1000°C have come from the depths into the outer crust in the liquid state. They have not only been injected into the crust but have also been poured out upon the earth's surface and the process is still going on, so that from time to time man has had the opportunity of seeing these molten rocks and even of measuring their temperature.

The earliest views as to the origin of this high temperature were that the earth had once been molten and was, indeed, still molten with the exception of a thin outer crust. With increasing knowledge of the physics of the earth it has been necessary to abandon this simple form of hypothesis. A modification was proposed by Kelvin in which blocks of the outer crust sank into the earth, at first remelting, but in doing so, gradually reducing the general temperature to a value where remelting was no longer



possible and thus bringing about a honeycombed-solid condition of the whole earth. With the attainment of this relatively stable mechanical condition, cooling took place almost solely by conduction and it was supposed that, with the aid of the present thermal gradient and the mathematical theory of heat conduction, temperatures at a depth could be calculated, as well as the lapse of time since this stable condition was established. The actual time so calculated turned out to be so short that geologists were unable to accept it as adequate for the formation of the known thickness of sedimentary beds and for the development of life as recorded in them [i.e. fossil evidence]. With the discovery of radioactivity and the determination of the quantities of radioactive substances in rocks, the source of heat thus supplied made it possible to abandon this embarrassingly short period of time. However, it led to a difficulty of another kind, for the actual amount of radioactive substances in surface rocks is such that, if these rocks extended to great depths, the heat being lost by the earth, as indicated by the thermal gradient, would be far less than that produced. The earth would thus be heating up.

### VITA BREVIS, MATHEMATICA LONGA

From "A Concise History of Mathematics," by Dirk J. Struik

The Paris milieu with its intense mathematical activity produced, around 1830, a genius of the first order, who, comet-like, disappeared as suddenly as he had appeared. Evariste Galois, the son of a small-town mayor near Paris, was twice refused admission to the Ecole Polytechnique and succeeded at last in entering the Ecole Normale only to be dismissed. He tried to make a living by tutoring mathematics, maintaining at the same time an uneasy balance between his ardent love for science and for democracy. Galois participated as a Republican in the Revolution of 1830, spent some months in prison, and was soon afterwards killed in a duel at the age of twenty-one. Two of the papers he sent for publication got lost on the editor's desk; some others were published long after his death. On the eve of the duel, he wrote to a friend a summary of his discoveries in the theory of equations. This pathetic document, in which he asked his friend to submit his discoveries to the leading mathematicians, ended with the words:

"You will publicly ask Jacobi or Gauss to give their opinion not on the truth, but on the importance of the theorems. After this there will be, I hope, some people who will find it to their advantage to decipher all this mess."

This mess ("ce gachis") contained no less than the theory of groups, the key to modern algebra and to modern geometry.

Galois' letter, as far as we know, was never submitted to Gauss or Jacobi. It never reached a mathematical public until Liouville published most of Galois' papers in his "Journal de Mathématiques" of 1846, at which period Cauchy had already begun to publish on group theory (1844-46). It was only then that some mathematicians began to be interested in Galois' theories. Full understanding of Galois' importance came only through Camille Jordan's "Traité des substitutions" (1870) and the subsequent publications by Klein and Lie. Now Galois' unifying principle has been recognized as one of the outstanding achievements of Nineteenth Century mathematics.

### THE IMPORTANCE OF A BELIEF IN RANDOM DISTRIBUTION

From "Foundations of Science," by Norman Robert Campbell

All chance distributions in any theory of chance are random distributions. How then are we to explain chance distributions that are not random? For chance is concerned whenever events are such that it cannot be predicted which of several alternatives will occur and yet each of these alternatives has a definite probability. Events which satisfy these conditions are not always equally probable. Thus, suppose that a stream of black and white balls is issuing from the end of a tube and I am examining their succession. I can find no law which will enable me to predict whether a white or a black ball will come next; on the other hand, black and white balls are not equally probable, for on the whole black preponderate and the ratio of their numbers tends, as the numbers tend to infinity, not to 1 but to 2. Here is a phenomenon in which chance is clearly concerned and yet is not characterized by a perfectly random distribution; the distribution is not such as would be produced by a voluntary agent selecting balls arbitrarily, or without any reference to their color.

One explanation is that the chance events may not be wholly due to chance; they may be due to the superimposition of some constant and regular law upon the results of a random distribution. And such doubtless would be the explanation that would be adopted here. We should probably suppose that the balls were being selected at random from a collection of balls, as they might be by an agent drawing them blindfold from a bag. The regularity of the result, the deviation of the numbers of black and white balls from a purely random distribution, is due to a regularity in the collection from which the balls are drawn at random; there are twice as many black balls as white balls in it.

The resolution of a distribution of unequally probable events into a random distribution of probable events and a law is familiar, but none the less extremely important. For it leads to the discovery of laws. If we did not believe that, if chance is involved at all, it must be involved in the form of a random distribution, we should have no reason for undertaking any analysis at all, and therefore no reason for believing that any regular law was involved in the matter.

### YES, BUT WHERE THERE'S SMOKE . . .

From "De Magnete," (1600) by Sir William Gilbert

Many are the fables about the loadstone, the errors and impotent reasonings of the philosophers, or the fairy-tales of mountebanks and story-tellers; as, for example, the questions raised by Franciscus Rueus about the loadstone, whether it is an imposture of cacodaemons; or the assertion that a loadstone placed unawares under the head of a sleeping woman drives her out of the bed if she be an adulteress; or that by its fume and vapor the loadstone is of use to thieves, as though the stone were by nature given to promote thefts; or that it withdraws bolts and opens locks, as Serapio insanely imagines; or that iron held by a loadstone's attraction, being placed in a balance, adds nought to the weight of the loadstone, as though the weight of the iron were absorbed by the virtue of the loadstone; or that, as Serapio and the Moors report, there are in Indian seas certain sharp-pointed rocks abounding in loadstone, which draw every nail out of ships that land alongside them and hold the vessels: this story, Olaus Magnus does not fail to recite: he tells of mountains in the North possessing such power of attraction, that ships have to be constructed with wooden pegs, so that as they sail by the magnetic cliffs there be no iron nails to draw out.

Others tell that in daytime the loadstone possesses the power of attracting iron, but that at night this power is feeble or rather null; that a white loadstone may be used as a philter, or that, as Abohali rashly asserts, when held in the hand it cures pains of the feet and cramps, or that, as Pictorius sings, it gives one favor and acceptance with princes or makes one eloquent. Ruelius writes that the loadstone's force, when failing or dulled, is restored by the blood of a buck; it has been said that a buck's blood frees the magnet from the diamond's sorcery, giving back its lost power when the magnet is bathed in the blood—this, because of the variance between that blood and the diamond; Arnoldus de Villanova fancies that the loadstone frees women from witchcraft and puts demons to flight; Marbodaeus, a Frenchman, fugleman of vain imaginings, says that it can make husbands agree-

able to wives and may restore wives to their husbands. In such-like follies and fables do philosophers of the vulgar sort take delight; with such-like do they cram readers a-hungry for things abstruse, and every ignorant gaper for nonsense.

### EXPERIMENT AND GEOMETRY

From "Science & Hypothesis," by Henri Poincaré

Can we maintain that certain phenomena which are possible in Euclidean space would be impossible in non-Euclidean space, so that experiment in establishing these phenomena would directly contradict the non-Euclidean hypothesis? I think that such a question cannot be seriously asked. Experiment plays a considerable role in the genesis of geometry; but it would be a mistake to conclude from that that geometry is, even in part, an experimental science. If it were experimental, it would only be approximate and provisory. And what a rough approximation it would be! Geometry would be only the study of the movements of solid bodies; but, in reality, it is not concerned with natural solids: its object is certain ideal solids, absolutely invariable, which are but a greatly simplified and very remote image of them. The concept of these ideal bodies is entirely mental, and experiment is but the opportunity which enables us to reach the idea. The object of geometry is the study of a particular "group"; but the general concept of group pre-exists in our minds, at least potentially. It is imposed on us not as a form of our sensitiveness, but as a form of our understanding; only, from among all possible groups, we must choose one that will be the *standard*, so to speak, to which we shall refer natural phenomena.

Experiment guides us in this choice, which it does not impose on us. It tells us not what is the truest, but what is the most convenient geometry. I challenge any one to give me a concrete experiment which can be interpreted in the Euclidean system, and which cannot be interpreted in the system of Lobatschewsky. As I am well aware that this challenge will never be accepted, I may conclude that no experiment will ever be in contradiction with Euclid's postulate; but, on the other hand, no experiment will ever be in contradiction with Lobatschewsky's postulate.

### THE VALUE OF ASTRONOMY

From "The Value of Science," by Henri Poincaré

Astronomy has taught us to set at naught appearances. The day Copernicus proved that what was thought the most stable was in motion, that what was thought moving was fixed, he

showed us how deceptive could be the infantile reasonings which spring directly from the immediate data of our senses. True, his ideas did not easily triumph, but since this triumph there is no longer a prejudice so inveterate that we can not shake it off. How can we estimate the value of the new weapon thus won?

The ancients thought everything was made for man, and this illusion must be very tenacious, since it must ever be combated. Yet it is necessary to divest oneself of it; or else one will be only an eternal myope, incapable of seeing the truth. To comprehend nature one must be able to get out of self, so to speak, and to contemplate her from many different points of view; otherwise we never shall know more than one side. Now, to get out of self is what he who refers everything to himself can not do. Who delivered us from this illusion? It was those who showed us that the solar system itself is only an imperceptible point in the infinite spaces of the stellar universe.

At the same time astronomy taught us not to be afraid of big numbers. This was needful, not only for knowing the heavens, but to know the earth itself; and was not so easy as it seems to us today. Let us try to go back and picture to ourselves what a Greek would have thought if told that red light vibrates four hundred millions of millions of times per second. Without any doubt, such an assertion would have appeared to him pure madness, and he never would have lowered himself to test it. Today an hypothesis will no longer appear absurd to us because it obliges us to imagine objects much larger or smaller than those our senses are capable of showing us, and we no longer comprehend those scruples which arrested our predecessors and prevented them from discovering certain truths simply because they were afraid of them. But why? It is because we have seen the heavens enlarging and enlarging without cease; because we know that the sun is 150 millions of kilometers from the earth and that the distances of the nearest stars are hundreds of thousands of times greater yet. Habituated to the contemplation of the infinitely great, we have become apt to comprehend the infinitely small. Thanks to the education it has received, our imagination, like the eagle's eye that the sun does not dazzle, can look truth in the face.

## THE PRINCIPLE OF COVARIANTS

From "The Philosophy of Space and Time,"  
by Hans Reichenbach

It was Ernst Mach who discovered the argument that can be constructed against Newton's theory of centrifugal force and which leads to a relativistic dynamics. Mach deals with the *pail experiment* described by Newton. A pail half full of water is sus-

pended by a rope and is put in a state of rotation by twisting the rope. In the beginning the pail will not drag along the water, but will rotate alone. Gradually, however, it will drag along the water, and the surface of the water will assume the well-known hollow shape, which is due to centrifugal force. When the pail is stopped, the water continues to rotate and retains its parabolic surface. Newton concludes that the centrifugal force cannot be explained by a relative motion, since a relative motion exists between the pail and the water at the beginning as well as at the end of the process, while the centrifugal forces appear only at the end. If the pail rotates while the water is at rest, there is no centrifugal force. If, however, the water rotates while the pail is at rest, there exists a centrifugal force.

Mach replies that Newton overlooked the fact that the surrounding masses of the earth and of the fixed stars have to be taken into consideration. The water rotates not only relative to the pail but also relative to these large masses, which may be considered as the cause of the centrifugal force. The centrifugal force therefore does not indicate a rotation relative to absolute space, but only a rotation relative to the masses of the universe. If we consider the water with its hollowed surface as being at rest, then the earth and the fixed stars rotate around the water. In this conception the centrifugal force is a *dynamic gravitational effect of rotating masses*. Such a force of traction originating in the rotation of masses can very well be conceived. A moving electric charge—as Einstein argued later—produces forces that do not exist when the charge is at rest.

What is new in Mach's interpretation is the idea that the inertial force can be interpreted in the relativistic conception as a dynamic gravitational effect. *Relativity can be extended to dynamics if forces are reinterpreted relativistically*. The same force that affects a body *K* as the result of the rotation of *K* according to one interpretation, affects it according to the other interpretation as the result of the rotation of *K*. We thus arrive at a complete reinterpretation of the concept of force (although Mach was not fully aware of it). Forces are not absolute magnitudes, but depend on the coordinate system. In physics there are both kinds of magnitudes; electric charge and entropy are *invariants*, i.e., magnitudes independent of the coordinate system; velocity and acceleration are *covariants*, i.e., depend on the coordinate system. This result, which represents the most significant aspect of Mach's view, expresses for the first time the basic idea of the principle of general covariance.



## CASTLES IN THE AIR

From "The Nature of Light and Colour in the Open Air,"  
by M. Minnaert

In a few very rare cases most remarkable mirages have been seen by quite reliable observers, who describe them as landscapes with towns and towers and parapets, rising above the horizon, transforming, crumbling, fairy-like scenes, producing a deep sense of happiness and an endless longing—*fata morgana*! No wonder that these observations, already so beautiful in themselves, have been adorned by the fancies of poetry and folk-lore.

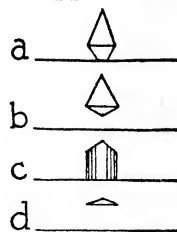


FIG. 46. How the *fata morgana* arises as a transition between the refraction of rays above warm and cold water.

Forel observed simpler forms of this phenomenon time and again above the Lake of Geneva, and after fifty years of study described it in detail. A calm surface of water ten to twenty miles across is essential, the eye must be 2 to 4 1/2 yards above the water, and, this being very important, the exact height must be found by experiment. In the afternoon on bright days when the water was warmer than the air, Forel saw four consecutive stages develop gradually along the opposite shore, the one succeeding the other, and remaining not

longer than 10 to 20 minutes in the same place.

These 4 stages were: (a) the mirage above warm water; reflection below the object; (b) the abnormal mirage above cold water; a very strange phenomenon, in which the object is seen quite normally, with its reflection below extremely compressed, (probably a labile, temporary, transition shape); (c) the castles in the air; the distant coast line is distorted over a distance of 10° to 20° (in angular measure) and elongated vertically into a row of rectangles (the 'streaked zone'); and (d) the normal curvature of the rays above cold water; no reflection is visible, but the object itself is strongly compressed in a vertical direction.

The upper horizon in the stages a and b and the lower horizon in stage d are the boundaries between which the vertical shading of the streaked zone is developed (Fig 47). The shifting

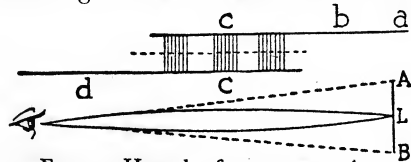


FIG. 47. How the *fata morgana* arises.

of the castles in the air is a result of refraction of type a being gradually replaced by type d. The theory that the density of the air, in a transition region of this kind, is greatest in layers of average height, seems quite acceptable. The path of the rays, in that case, is that shown in Fig 47, and, as will be seen, every point of light L is drawn out vertically into a line AB.

## STRAIGHT (?) LINES AND CONVEX MIRRORS

Quoted in "On Mathematics and Mathematicians,"  
by Robert Edouard Moritz

Think of the image of the world in a convex mirror. . . . A well-made convex mirror of moderate aperture represents the objects in front of it as apparently solid and in fixed positions behind its surface. But the images of the distant horizon and of the sun in the sky lie behind the mirror at a limited distance, equal to its focal length. Between these and the surface of the mirror are found the images of all the other objects before it, but the images are diminished and flattened in proportion to the distance of their objects from the mirror. . . . Yet every straight line or plane in the outer world is represented by a straight [?] line or plane in the image. The image of a man measuring with a rule a straight line from the mirror, would contract more and more the farther he went, but with his shrunken rule the man in the image would count out exactly the same number of centimeters as the real man. And, in general, all geometrical measurements of lines and angles made with regularly varying images of real instruments would yield exactly the same results as in the outer world, all lines of sight in the mirror would be represented by straight lines of sight in the mirror. In short, I do not see how men in the mirror are to discover that their bodies are not rigid solids and their experiences good examples of the correctness of Euclidean axioms. But if they could look upon our world as we look into theirs without overstepping the boundary, they must declare it to be a picture in a spherical mirror, and would speak of us just as we speak of them; and if two inhabitants of the different worlds could communicate with one another, neither, as far as I can see, would be able to convince the other that he had the true, the other the distorted, relation. Indeed I cannot see that such a question would have any meaning at all, so long as mechanical considerations are not mixed up with it.

H. HELMHOLTZ

## A SAD STORY

From "Hoaxes," by Curtis D. MacDougall

Of the ubiquitous tendency to persist in believing falsehood because to be incredulous would involve the embarrassing and psychologically difficult experience of abandoning a preconceived idea, or pet theory, there is no better illustration than that of the Würzburg stones by which the students of Johann Bartholomaeus Adam Beringer, early eighteenth century professor of natural philosophy, enabled him to ruin his own career.

At the time the most important subject occupying the attention

of the scientific world was the nature of fossils, and Dr. Beringer, an intensely religious man, had advanced an original theory that they were merely "capricious fabrications of God," hidden in the earth for some inscrutable purpose, possibly to test the faith of man. So great an obsession did gaining acceptance of this theory become with him that his students at the University of Würzburg wearied of listening to its exposition. So, when one of them came across the account of a joke which the students of Athanasius Kircher, seventeenth century German mathematician and scientist, had played on him, they decided to emulate it.

On the side of a hill where the good professor took his classes in search of geological specimens, Dr. Beringer's students planted absurd clay tablets bearing inscriptions in Hebrew, Babylonian, Syriac and Arabic. Becoming bolder after a few preliminary successes, they inscribed the signature of God himself on one of the "fossils."

Beringer was astounded and elated. He saw in the finds proofs of his theory and immediately began preparation of a tome in Latin. At great expense he had engravings made of the finds and prepared an elaborate scholarly description and explanation of them.

The jokers uneasily began to realize they had gone too far and confessed to the professor. The result was entirely the opposite of that expected; Beringer refused absolutely to believe them. Instead, he accused them of attempting to rob him of the honor of a great discovery and went ahead with his book. It appeared in 1728, entitled *Lithographiae Wirceburgensis*, and contained an ingenious allegorical frontispiece, a title page devoted entirely to the author's previous scholarship, a nine-page dedication to Dr. Christopher Francis, prince bishop of Würzburg, a preface of about the same length, fourteen chapters forming the body of the book, and twenty-one plates of the figures.

The objections of his friends and the charge of a hoax, Beringer dismissed; and he demonstrated how the finds proved his previously announced theory as to the nature of fossils and refuted the idea that the inscriptions might be vestiges of early "pagan occupation of the land," meaning the Gauls.

The shout of laughter which greeted the book was too much even for Beringer. The remainder of his fortune went to buying back all existent copies. He died broken-hearted.

### CRYSTALLOGRAPHY AND A HAPPY MISFORTUNE

From "The Birth and Development of the Geological Sciences,"  
by Frank Dawson Adams

Among other accomplishments René-Just Haüy (1743-1821) became a good botanist and one day when walking through the

Royal Gardens in Paris, which he visited frequently in the prosecution of his studies in this subject, he saw a large number of people crowding into a lecture hall where the aged Daubenton was to give one of his charming popular lectures on mineralogy. This lecture turned Haüy's attention from botany to mineralogy.

The constancy of the complicated forms displayed by the various flowers and fruits had always impressed him and he felt sure that a similar law of constancy must prevail in the various species of the mineral kingdom, in spite of the almost bewildering variety of forms which their crystals exhibit. His mind was filled with this idea and one day when examining some minerals in the collection of one of his friends, by what may be termed a happy misfortune, a fine group of prismatic calcite crystals slipped from his hand, fell to the floor and one of the crystals was broken. On examining this broken prism Haüy noticed that it had assumed a new form bounded by faces as smooth and shining as those of the original prism, and to his great surprise he found that this form was identical with that presented by the rhombic prisms of Iceland Spar. A new light broke upon the subject. He returned home, and, selecting from his collection a number of calcite crystals, some prisms, some scalenohedrons and others of the diverse forms in which this mineral crystallizes, he broke them all and found that the resulting cleavage form was in every case that of a rhombohedron. "Tout est trouvé," he exclaimed, all the molecules of calcite have one and the same form, and it is merely the manner in which they are grouped that gives rise to the various external forms which this mineral displays. If this be the true principle of crystallization other minerals should also show analogous cleavage forms revealing their internal structure. In the pursuit of knowledge he did not hesitate to break up all the crystals in his own collection and all which he could obtain from his confiding friends. In all species, at least in those which displayed a cleavage, he believed that he could find some nuclear form about which its crystals had been built up and from which their angles might be predicted before they were actually measured.

### AN INTRODUCTION TO THE DANCE

From "The Behaviour and Social Life of Honeybees,"  
by Ronald Ribbands

The dancing of bees had often been seen by beekeepers, and variously interpreted, but it was generally believed to be a means of showing that new honey or pollen had been discovered (Root, E., 1908); there were additional observations (Bonnier, 1906) which suggested that successful foragers might be able to inform their companions of the whereabouts of their booty. Then the

work of V. Frisch proved that the dances were performed by successful foragers, and that they excited their comrades to fly out to search for the food which the dancers had been collecting. These observations were published in a series of articles (1920-22), then in detail (1923), and then summarized (1924). They proved that the dancers communicate the presence of food, and the odour at its source. Later work (1946-50) showed that they also communicate the distance and direction of the source from the hive.

V. Frisch (1923) watched individually marked bees in an observation hive, and described two kinds of dance, one performed by nectar collectors and the other by pollen gatherers. He described the former thus (1924): "After she has given her sweet booty to her comrades, she begins a kind of round-dance in which she runs round and round in a circle with quick tripping steps, then suddenly turns round and revolves in the opposite direction, and so on. From 3 to 20 reversals may be made at one place, and the dance may take from a couple of seconds to even a whole minute. It is often repeated on different parts of the comb. Since this round-dance takes place in the midst of a crowd of other bees, the circling dancer comes into close contact with her comrades; these become greatly excited, and turn their heads towards her, trying to keep their antennae touching her abdomen and to trip behind her, so that the dancer draws after her a tail of other bees which accompany her in all the revolutions of the dance. Then the dancer flies alone to the feeding-place, and the newcomers, as though called up by magic out of a trap-door, gather there with her."

Of the second dance, he said, "The pollen-collectors also dance if they have found plentiful supplies. However, their dance is different. Especially characteristic of it is a wagging movement of the dancer by which she formally beats her following comrades on their faces and antennae with her pollen loads."

### A DISTASTEFUL THEORY

From "The Genetical Theory of Natural Selection,"  
by Ronald A. Fisher

An important question raised by theories of mimicry concerns the process by which nauseous flavours, as a means of defence, have been evolved. Most other means of defence such as stings, or disagreeable secretions and odours, are explicable by increasing the chance of life of the individuals in which they are best developed, or of the social community to which they belong. With distastefulness, however, although it is obviously capable of giving protection to the species as a whole, through its effect upon the instinctive or acquired responses of predators,

yet since any individual tasted would seem almost bound to perish, it is difficult to perceive how individual increments of the distasteful quality, beyond the average level of the species, could confer any individual advantage.

The gregarious habit of certain larvae supplies a possible solution of the problem, if we are willing to accept the view that the distasteful quality of the imago, which warning colours are so well adapted to advertise, is itself merely a by-product due to the persistence of nauseous substances acquired through the protection afforded to the larva. For, although with the adult insect the effect of increased distastefulness upon the actions of the predator will be merely to make that individual predator avoid all members of the persecuted species, and so, unless the individual attacked possibly survives, to confer no advantage upon its genotype, with gregarious larvae the effect will certainly be to give the increased protection especially to one particular group of larvae, probably brothers and sisters of the individual attacked. The selective potency of the avoidance of brothers will of course be only half as great as if the individual itself were protected; against this is to be set the fact that it applies to the whole of a possibly numerous brood. There is thus no doubt of the real efficacy of this form of selection, though it may well be doubted if all cases of insect distastefulness can be explained by the same principle.

### THE EMINENT FITNESS OF SWINE

From "Elements of Mathematical Biology," by Alfred J. Lotka

Clearly, a species may hold its own, in the struggle for existence, either by the aid of well-developed protective devices resulting in a low death rate, and requiring only a correspondingly low birth rate; or, a less well protected species may balance a high death rate by an equally high birth rate. Which of these two methods would be chosen in the natural course of events is a question that it might be difficult to answer on any general *a priori* principle, so long as attention remained fixed on a single species. Perhaps one would have expected evolution to turn in the favor of the more economical method of meeting a low death rate with a low birth rate. In point of fact both types of organism—the economical type (as judged by its own standard) with low death rate, and the wasteful with high death rate—exist side by side in abundance. This is a good example to illustrate the purely relative character of fitness, and to remind us once more that we cannot expect any success in attempts to define the direction of evolution in terms of a single species. It is not the individual species, the individual components of the system, that

evolve, but the system as a whole, comprising all the species and their environment. The species of the economical type, with low death rate, are largely dependent for their subsistence on the presence of species of the opposite type; we must think here of a competition, not between individual species, but between groups of species, groups consistent, in the simplest case, of two species each, a food species or prey, and a feeding or predatory species. Of two such *groups*, that one will, other things equal, have the advantage in the struggle, in which the high productivity of the food species is accompanied by economy of life on the part of the feeding species. From the point of view of the hog, so to speak, the high mortality in the pen is a disastrous inefficiency and maladaptation, a misfortune to be borne, as best it may, with porcine philosophy. From the point of view of the consumer, on the other hand, this high mortality is, quite on the contrary, a measure of the efficiency, the eminent fitness of swine as producers of pork; and his only regret is that so much of the feed placed in the trough goes merely to carry on "what may be called the personal activities of the animals themselves"—to borrow the felicitious phrase of an anonymous writer on the editorial page of the New York Times.

## THE CARE AND FEEDING OF CRYSTALS

From "Concerning the Nature of Things," by Sir William Bragg

We may ask ourselves why, if the natural arrangement of molecules is regular, we do not find all bodies in crystalline form. To this we must answer that in the first place a large perfect crystal must grow from a single nucleus. It is difficult to say what first arrests the relative motion of two or three molecules of the cooling liquid, joining them together and making a beginning to which other molecules become attached. Perhaps it is a mere accident of their meeting; perhaps some minute particle of foreign matter is present which serves as a base, or some irregularity on the wall of the containing vessel. If there are very many nuclei present in the liquid, very many crystals will grow; and since they are not likely to be orientated to each other when they meet, they will finally form an indefinite mass of small crystals, not a single crystal. They may be so small that to the eye the whole appears as a solid mass without any regularity of form. In order that a large perfect crystal should be formed, the arrangements must be such that the molecules find few centres on which to grow. And they must grow, usually, very slowly and quietly, so that each molecule has time to settle itself correctly in its proper place. The molecules must have enough movement to permit of this adjustment. These conditions are well shown in the

methods which the crystallographer employs for the growth of crystals. If, for example, he is growing a large crystal of salt from a solution of brine, he will suspend a minute, well-formed crystal in the brine, and he will keep the temperature of the latter so carefully adjusted that the atoms of sodium and chlorine are only tempted to give up their freedom when they meet an assemblage of atoms already in perfect array—that is to say, when they come across the suspended crystal. If the solution is too hot, the suspended crystal will be dissolved in the unsaturated solution; if it is too cold, crystals will begin to grow at many points. Sometimes the liquid is kept in gentle movement so that various parts of it are brought to the suspended crystal in due turn. The principal conditions are time and quiet, a solution of the salt just ready to precipitate its contents, temperature and strength of solution being properly adjusted for the purpose, the presence of a small perfect crystal and the gentle movement of the solution past it. We do not, of course, quite understand how these or some such conditions come to be realised during the growth of a diamond or a ruby; but we find them to be necessary in the laboratory when we attempt to grow crystals ourselves.

When the conditions are fulfilled in part only, we may get a mass of minute crystals in disarray; we may even find a totally irregular structure—an amorphous substance, to employ the usual phrase. This alone would account for the seeming rarity of crystals, and we have also to bear in mind that many bodies are highly composite in character, consisting of many substances each of which has its own natural form.

## THE NOBLE LUXURY

From "Science Theory and Man," by Erwin C. Schrödinger

Play, art and science are the spheres of human activity where action and aim are not as a rule determined by the aims imposed by the necessities of life; and even in the exceptional instances where this is the case, the creative artist or the investigating scientist soon forget this fact—as indeed they must forget it if their work is to prosper. Generally, however, the aims are chosen freely by the artist or student himself, and are superfluous; it would cause no immediate harm if these aims were not pursued. What is operating here is a surplus force remaining at our disposal beyond the bare struggle for existence: art and science are thus luxuries like sport and play, a view more acceptable to the beliefs of former centuries than to the present age. It was a privilege of princes and flourishing republics to draw artists and scientists within their sphere, and to give them a living in exchange for an activity which yielded nothing save entertainment,



interest and repute for the prince or the city. In every age such procedure has been regarded as a manifestation of internal strength and health, and the rulers and peoples have been envied who could afford to indulge in this noble luxury, this source of pure and lofty pleasure.

### GEOMETRY AT PLAY

From "The Works of Archimedes," edited by T. L. Heath

After his return to Syracuse Archimedes lived a life entirely devoted to mathematical research. Incidentally he made himself famous by a variety of ingenious mechanical inventions. These things were however, merely the "diversions of geometry at play," and he attached no importance to them.

Some of his mechanical inventions were used with great effect against the Romans during the siege of Syracuse. Thus he contrived catapults so ingeniously constructed as to be equally serviceable at long or short ranges, machines for discharging showers of missiles through holes made in the walls, and others consisting of long moveable poles projecting beyond the walls which either dropped heavy weights upon the enemy's ships, or grappled the prows by means of an iron hand or a beak like that of a crane, then lifted them into the air and let them fall again. Marcellus is said to have derided his own engineers and artificers with the words, "Shall we not make an end of fighting against this geometrical Briareus who, sitting at ease by the sea, plays pitch and toss with our ships to our confusion, and by the multitude of missiles that he hurls at us outdoes the hundred-handed giants of mythology?"; but the exhortation had no effect, the Romans being in such abject terror that "if they did but see a piece of rope projecting above the wall, they would cry 'there it is again,' declaring that Archimedes was setting some engine in motion against them, and would turn their backs and run away, insomuch that Marcellus desisted from all conflicts and assaults, putting all his hopes in a long siege."

### MATHEMATICIANS ARE NOT ALWAYS RIGHT

From "A Philosophical Essay on Probabilities,"  
by Pierre Simon, Marquis de Laplace

While induction often leads to the discovery of the general principles of the sciences, it does not always suffice to establish them absolutely. It is always necessary to confirm them by demonstrations or by decisive experiences; for the history of the sciences

shows us that induction has sometimes led to inexact results. I shall cite, for example, a theorem of Fermat in regard to prime numbers. This great geometrician, who had meditated profoundly upon this theorem, sought a formula which, containing only prime numbers, gave directly a prime number greater than any other number assignable. Induction led him to think that two, raised to a power which was itself a power of two, formed with unity a prime number. Thus, two raised to the square plus one, forms the prime number five; two raised to the second power of two, or sixteen, forms with one the prime number seventeen. He found that this was still true for the eighth and the sixteenth power of two augmented by unity; and this induction, based upon several arithmetical considerations, caused him to regard this result as general. However, he avowed that he had not demonstrated it. Indeed, Euler recognized that this does not hold for the thirty-second power of two, which, augmented by unity, gives 4,294,967,297, a number divisible by 641.

### SCIENCE AND VAIN SPECULATION

From "The Principles of Science," by W. Stanley Jevons

It would be an error to suppose that the great discoverer seizes at once upon the truth, or has any unerring method of divining it. In all probability the errors of the great mind exceed in number those of the less vigorous one. Fertility of imagination and abundance of guesses at truth are among the first requisites of discovery; but the erroneous guesses must be many times as numerous as those which prove to be well founded. The weakest analogies, the most whimsical notions, the most apparently absurd theories, may pass through the teeming brain, and no record remain of more than the hundredth part. There is nothing really absurd except that which proves contrary to logic and experience. The truest theories involve suppositions which are inconceivable, and no limit can really be placed to the freedom of hypothesis.

Kepler is an extraordinary instance to this effect. No minor laws of nature are more firmly established than those which he detected concerning the orbits and motions of planetary masses, and on these empirical laws the theory of gravitation was founded. Did we not learn from his own writings the multitude of errors into which he fell, we might have imagined that he had some special faculty of seizing on the truth. But, as is well known, he was full of chimerical notions; his favorite and long-studied theory was founded on a fanciful analogy between the planetary orbits and the regular solids. His celebrated laws were the outcome of a lifetime of speculation, for the most part vain and

groundless. We know this because he had a curious pleasure in dwelling upon erroneous and futile trains of reasoning, which most persons consign to oblivion. But Kepler's name was destined to be immortal, on account of the patience with which he submitted his hypothesis to comparison with observation, the candour with which he acknowledged failure after failure, and the perseverance and ingenuity with which he renewed his attack upon the riddles of nature.

### WELL . . . NOBODY'S PERFECT

Quoted in "On Mathematics and Mathematicians,"  
by Robert Edouard Moritz

On one occasion, when he [Newton] was giving a dinner to some friends at the university, he left the table to get them a bottle of wine; but, on his way to the cellar, he fell into reflection, forgot his errand and his company, went to his chamber, put on his surplice, and proceeded to the chapel. Sometimes he would go into the street half dressed, and on discovering his condition, run back in great haste, much abashed. Often, while strolling in his garden, he would suddenly stop, and then run rapidly to his room, and begin to write, standing, on the first piece of paper that presented itself. Intending to dine in the public hall, he would go out in a brown study, take the wrong turn, walk a while, and then return to his room, having totally forgotten the dinner. Once having dismounted from his horse to lead him up a hill, the horse slipped his head out of the bridle; but Newton oblivious, never discovered it till, on reaching a tollgate at the top of the hill, he turned to remount and perceived that the bridle which he held in his hand had no horse attached to it. His secretary records that his forgetfulness of his dinner was an excellent thing for his old housekeeper, who "sometimes found both dinner and supper scarcely tasted of, which the old woman has very pleasantly and mumpingly gone away with." On getting out of bed in the morning, he has been discovered to sit on his bedside for hours without dressing himself, utterly absorbed in thought.

JAMES PARTON

### OF COURSE, WE DON'T TALK ABOUT GALOIS

Quoted in "On Mathematics and Mathematicians,"  
by Robert Edouard Moritz

This [the fact that the pursuit of mathematics brings into harmonious action all the faculties of the human mind] accounts for the extraordinary longevity of all the greatest masters of the

Analytic art, the Dii Majores of the mathematical Pantheon. Leibnitz lived to the age of 70; Euler 76; Lagrange to 77; Laplace to 78; Gauss to 78; Plato, the supposed inventor of the conic sections, who made mathematics his study and delight, who called them the handles or aids to philosophy, the medicine of the soul, and is said never to have let a day go by without inventing some new theorems, lived to 82; Newton, the crown and glory of his race, to 85; Archimedes, the nearest akin, probably, to Newton in genius, was 75, and might have lived on to be 100, for aught we can guess to the contrary, when he was slain by the impatient and ill-mannered sergeant, sent to bring him before the Roman general, in the full vigour of his faculties, and in the very act of working out a problem; Pythagoras, in whose school, I believe, the word mathematician (used, however, in a somewhat wider than its present sense) originated, the second founder of geometry, the inventor of the matchless theorem which goes by his name, the precognizer of the undoubtedly mis-called Copernican theory, the discoverer of the regular solids and the musical canon who stands at the very apex of this pyramid of fame, (if we may credit the tradition) after spending 22 years studying in Egypt, and 12 in Babylon, opened school when 56 or 57 years old in Magna Graecia, married a young wife when past 60, and died, carrying on his work with energy unspent to the last, at the age of 99. The mathematician lives long and lives young; the wings of his soul do not early drop off, nor do its pores become clogged with the earthy particles blown from the dusty highways of vulgar life.

J. J. SYLVESTER

### NEWTON vs GAUSS

Quoted in "On Mathematics and Mathematicians,"  
by Robert Edouard Moritz

Two extreme views have always been held as to the use of mathematics. To some, mathematics is only measuring and calculating instruments, and their interest ceases as soon as discussions arise which cannot benefit those who use the instruments for the purposes of application in mechanics, astronomy, physics, statistics, and other sciences. At the other extreme we have those who are animated exclusively by the love of pure science. To them pure mathematics, with the theory of numbers at the head, is the only real and genuine science, and the applications have only an interest in so far as they contain or suggest problems in pure mathematics.

Of the two greatest mathematicians of modern times, Newton and Gauss, the former can be considered as a representative of the first, the latter of the second class: neither of them was



exclusively so, and Newton's inventions in the science of pure mathematics were probably equal to Gauss's work in applied mathematics. Newton's reluctance to publish the method of fluxions invented and used by him may perhaps be attributed to the fact that he was not satisfied with the logical foundations of the Calculus; and Gauss is known to have abandoned his electrodynamic speculations, as he could not find a satisfying physical basis. . . .

Newton's greatest work, the "Principia," laid the foundation of mathematical physics; Gauss's greatest work, the "Disquisitiones Arithmeticae," that of higher arithmetic as distinguished from algebra. Both works, written in the synthetic style of the ancients, are difficult, if not deterrent, in their form, neither of them leading the reader by easy steps to the results. It took twenty or more years before either of these works received due recognition; neither found favour at once before that great tribunal of mathematical thought, the Paris Academy of Sciences. . . .

The country of Newton is still pre-eminent for its culture of mathematical physics, that of Gauss for the most abstract work in mathematics.

J. T. MERZ

### A FEW QUOTES AND OBSERVATIONS

Quoted in "On Mathematics and Mathematicians,"  
by Robert Edouard Moritz

In questions of science the authority of a thousand is not worth the humble reasoning of a single individual.

GALILEO

I don't know what I may seem to the world, but, as to myself, I seem to have been only as a boy playing in the seashore, and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me.

NEWTON

Mathematics is the queen of the sciences and arithmetic the queen of mathematics. She often condescends to render service to astronomy and other natural sciences, but in all relations she is entitled to the first rank.

GAUSS

Taking mathematics from the beginning of the world to the time when Newton lived, what he had done was much the better half.

LEIBNITZ

Before the introduction of the Arabic notation, multiplication was difficult, and the division even of integers called into play the highest mathematical faculties. Probably nothing in the modern world could have more astonished a Greek mathematician than to learn that, under the influence of compulsory education, the whole population of Western Europe, from the highest to the lowest, could perform the operation of division for the largest numbers. This fact would have seemed to him a sheer impossibility. . . . Our modern power of easy reckoning with decimal fractions is the most miraculous result of a perfect notation.—

A. N. WHITEHEAD

Once when lecturing to a class he [Lord Kelvin] used the word "mathematician," and then interrupting himself asked his class: "Do you know what a mathematician is?" Stepping to the blackboard he wrote upon it:—

$$\int_{-\infty}^{+\infty} e^{-x^2} dx = \sqrt{\pi}$$

Then putting his finger on what he had written, he turned to his class and said: "A mathematician is one to whom *that* is as obvious as that twice two makes four is to you."

S. P. THOMPSON

Nature and Nature's laws lay hid in night:  
God said, "Let Newton be!" and all was light.

A. POPE

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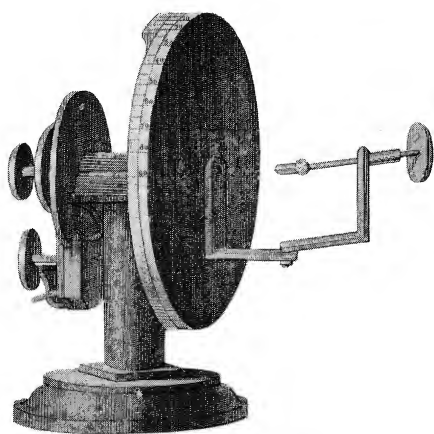
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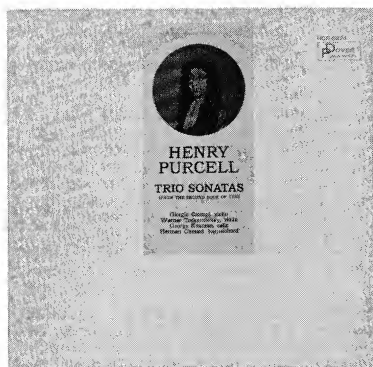
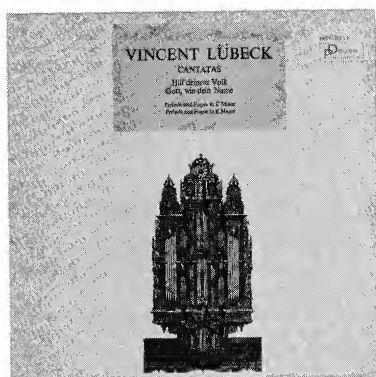
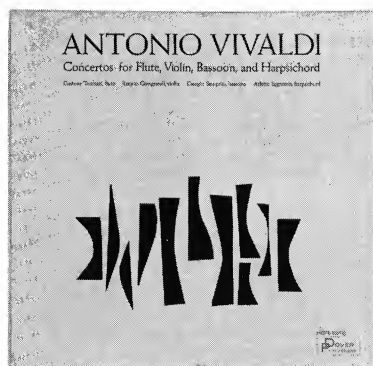
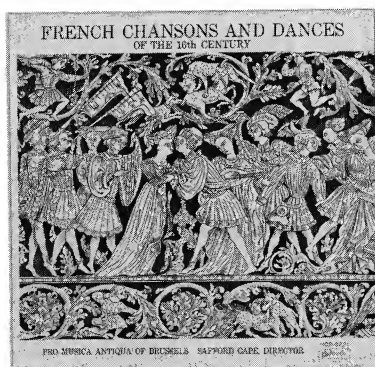
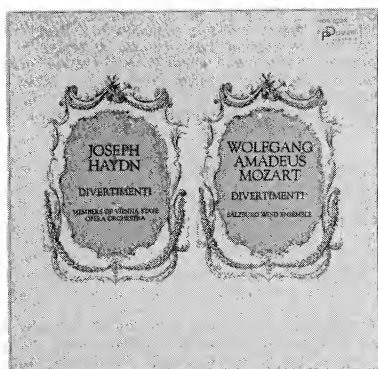
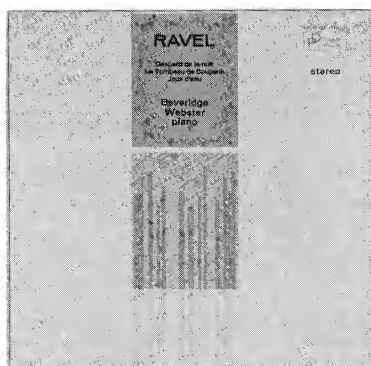
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**HAYDN: DIVERTIMENTI FOR WIND BAND, IN C; IN F; DIVERTIMENTO A NOVE STROMENTI IN C FOR STRINGS AND WIND INSTRUMENTS,** reconstructed by H. C. Robbins Landon, performed by members of Vienna State Opera Orch.; **MOZART DIVERTIMENTI IN C, III (K. 187) AND IV (K. 188),** Salzburg Wind Ensemble. Robbins Landon discovered Haydn manuscripts in a Benedictine monastery in Lower Austria, edited them and restored their original instrumentation. The result is this magnificent record. Two little-known divertimenti by Mozart—of great charm and appeal—are also included. None of this music is available elsewhere (Playing time 58 mins.) HCR 5223 \$2.00

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**BARTOK: VIOLIN CONCERTO; SONATA FOR UNACCOMPANIED VIOLIN,** Ivry Gitlis, Pro Musica of Vienna, under Hornstein. Both these works are outstanding examples of Bartok's final period, and they show his powers at their fullest. The Violin Concerto is, in the opinion of many authorities, Bartok's finest work, and the Sonata, his last work, is "a masterpiece" (F. Sackville West). "Wonderful, finest performance of both Bartok works I have ever heard," GRAMOPHONE. "Gitlis makes such potent and musical sense out of these works that I suspect many general music lovers (not otherwise in sympathy with modern music) will discover to their amazement that they like it. Exceptionally good sound," AUDITOR. (Playing time 54 mins.) HCR 5211 \$2.00

**J. S. BACH: PARTITAS FOR UNACCOMPANIED VIOLIN: #2 in D Minor and #3 in E,** Bronislav Gimpel. Bach's works for unaccompanied violin fall within the same area that produced the Brandenburg Concerti, the Orchestral Suites, and the first part of the Well-Tempered Clavichord. The D Minor is considered one of Bach's masterpieces; the E Major is a buoyant work with exceptionally interesting baroque effects. This is the first release of a truly memorable recording by Bronislav Gimpel, "as a violinist, the equal of the greatest" (P. Leron, in OPERA, Paris). (Playing time 53 mins.) HCR 5212 \$2.00

**ROSSINI: QUARTETS FOR WOODWINDS: #1 IN F, #4 IN B FLAT, #5 IN D, AND #6 IN F, N. Y. Woodwind Quartet Members: S. Baron, Flute, J. Barrows, French Horn; B. Garfield, Bassoon; D. Glazer, Clarinet.** Rossini's great genius was centered in the opera, but he also wrote a small amount of first-rate non-vocal music. Among these instrumental works, first place is usually given to the very interesting quartets. Of the three different surviving arrangements, this wind group version is the original, and this is the first recording of these works. "Each member of the group displays wonderful virtuosity when the music calls for it, at other times blending sensitively into the ensemble," **HIGH FIDELITY.** "Sheer delight," Philip Miller. (Playing time 45 mins.) **HCR 5214 \$2.00**

**TELEMANN: THE GERMAN FANTASIAS FOR HARPSICHORD (#1-12), Helma Elsner.** Until recently, Georg Philip Telemann (1681-1767) was one of the mysteriously neglected great men of music. Recently he has received the attention he deserved. He created music that delights modern listeners with its freshness and originality. These fantasias are free in form and reveal the intricacy of thorough bass music, the harmonic wealth of the "new music," and a distinctive melodic beauty. "This is another blessing of the contemporary LP output. Miss Elsner plays with considerable sensitivity and a great deal of understanding," **REV. OF RECORDING MUSIC.** "Fine recorded sound," Harold Schonberg. "Recommended warmly, very high quality," **DISQUES.** (Playing time 50 mins.) **HCR 5215 \$2.00**



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**RAVEL: GASPARD DE LA NUIT, LE TOMBEAU DE COUPERIN, JEUX D'EAU,** Beveridge Webster, Piano. Webster studied under Ravel and played his works in European recitals, often with Ravel's personal participation in the program. This record offers examples of the three major periods of Ravel's pianistic work, and is a must for any serious collector or music lover. (Playing time about 50 minutes.) **Monaural HCR 5213 \$2.00**

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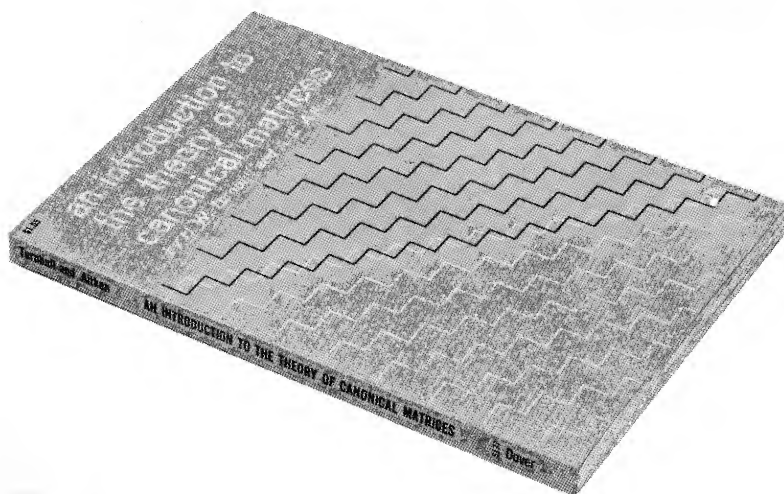
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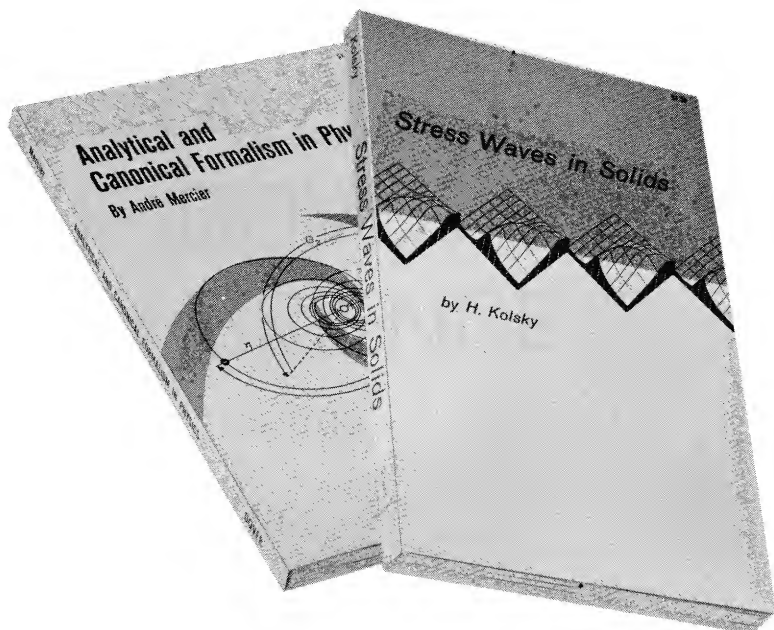
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Vivaldi, Antonio 87



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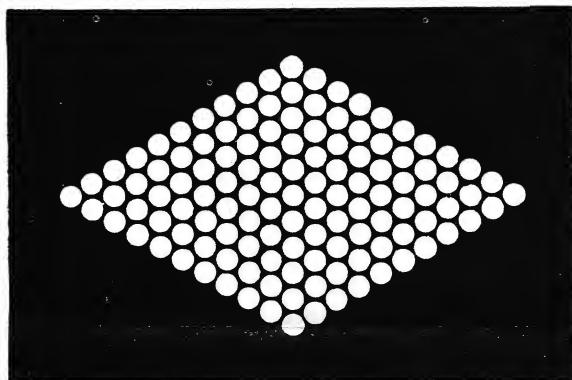
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NOW AVAILABLE FROM DOVER...A FASCINATING EXCURSION INTO ONE OF THE  
BORDERLANDS OF POPULAR SCIENCE!

Dear Dover Reader:

While we were working on some advertising material for a new Dover book, I  
came upon a strange phenomenon.

Take a look  
at this diagram:



It was taken from a brand-new Dover reprint -- a book that explores one of the  
most intriguing realms of science I have ever delved into:

VISUAL ILLUSIONS: Their Causes, Characteristics & Appli-  
cations by M. Luckiesh. New introduction prepared by  
William H. Ittleson, Department of Psychology, Brooklyn  
College, New York. 100 figures. Index. Bibliography.  
xxi + 252pp. 5 3/8 x 8 1/2. Paperbound \$1.50

According to the author of this book, a lighting engineer who had a life-long  
interest in the psychology of vision and in the aesthetics of light and color,  
the diagram above is supposed to be an optical illusion. But is it? My own first  
reaction was to ask exactly what was supposed to happen. My second was to think that  
it was a mistake. Nothing happened at all.

But some questioning revealed that half the people in our office saw this figure as  
a genuine illusion. To them, the circles within the triangle "vibrated," or "jangled  
together," or their pattern shifted constantly as one looked at them.

What happens when you look at it?

Why the different reactions? I don't know. Perhaps wearing or not wearing glasses  
has something to do with it. Perhaps it has something to do with eye defects, or  
with powers of concentration, or with psychological differences in the way people  
look at things.

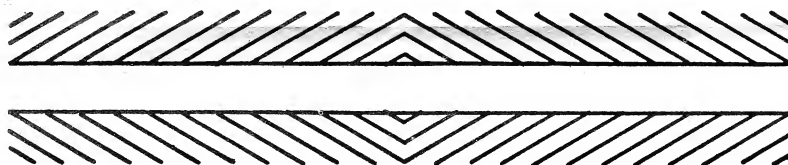
(Over, please)

At any rate, it certainly does illustrate the truth of the opening sentence of this remarkable book. "Seeing is deceiving" wrote Luckiesh, and from this premise he went on to write a book that, since its original publication in 1922, has built itself a reputation among psychologists and the growing number of students of perception as the finest summary of the phenomena associated with optical illusions.

But the book is obviously much more than that. Nowadays, with the development of so-called "op" art and with the revolution in movie-making, we are all more aware than ever that we don't always see accurately...that it is easy to fool the eye... that optical tricks can be used in painting as in magic. This book is by far the best description and non-technical explanation of these phenomena in print.

Order your copy right away...don't delay!

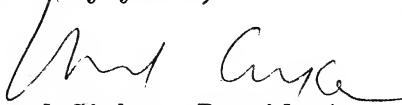
If your curiosity is aroused as much as mine was, then read through Luckiesh's text for yourself and look at the dozens of other illusions he includes as illustration. Like this one, which seems to work for everyone:



Take it from a layman, you'll be fascinated. And take it from a businessman, this book is going to sell briskly, especially at this time of year. I urge you not to delay. Stocks are plentiful right now, so order your copy -- or copies -- of Luckiesh: VISUAL ILLUSIONS while there's still time to get them for the holiday season.

And try that diagram on a few friends. The results might prove very interesting.

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Luckiesh/ind/letter